Economic and Social Commission for Asia and the Pacific

Water Resources Journal

E/ESCAP/SER.C/129

June 1981 (Quarterly)

United Nations

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ABBREVIATIONS USED IN THIS ISSUE

^{o}C	degrees Celsius	mb	millibar
E	east	mi	mile
ft	foot	mi/sec	miles per second
gpd	gallons per day	mi^3/sec	cubic miles per second
gpm	gallons per minute	mm	millimetre
GWh	gigawatt hour	mm/h	millimetres per hour
ha	hectare	MSLP	minimum sea-level pressure
hr	hour	MW	megawatt
JTWC	Joint Typhoon Warning Center, Guam	N	north
		naut mi	nautical mile
km	kilometre	S	south
kn	knot	sec	second
kW	kilowatt	TC	tropical cyclone
l	litre	TCFA	tropical cyclone formation alert
l/s	litres per second	TD	tropical depression
m	metre	W	west

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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INTRODUCTION

Data on tropical cyclones, floods and droughts, and on the major damage which they have caused, in various countries and areas in the ESCAP region have been published annually in the *Water Resources Journal* since 1952. This issue contains information on such meteorological disasters which occurred in the region during 1980.

The first section of this issue reviews the general characteristics of world weather during 1980. This global perspective is followed in the second section by a general resumé of the tropical cyclones that developed during 1980 over the western North Pacific Ocean and the Bay of Bengal region. Each of the major typhoons which caused heavy damage to countries along its track is described in the narratives in the third section. The fourth section presents reports on the damage caused by cyclones, floods and droughts during 1980 in individual countries and areas. Following these country reports is a retrospective review of meteorological events and damages which occurred before 1980 in a few countries. The final section of this issue contains accounts of control measures taken by selected countries in the region, and news features on topics related to the central concern of this issue: damages caused by tropical cyclones, floods and droughts.

Most of the data have been supplied by the departments responsible in the countries or areas concerned, and the ESCAP secretariat takes this opportunity to thank them for their co-operation. Special acknowledgement is made of the *Annual Typhoon Report, 1980* of the United States Naval Oceanography Command Center/Joint Typhoon Warning Center (JTWC) at Guam, in the Pacific Ocean, from which the tracks of typhoons and narratives of destructive individual typhoons have been reproduced in this issue.

I. GENERAL CHARACTERISTICS OF WORLD WEATHER DURING 1980*

A. NORTHERN HEMISPHERE

The mean circulation at the 700-mb level during the winter (December 1979 to February 1980) featured pronounced north-south waves and strong westerlies that were displaced well south of their usual position. The most noteworthy feature was a large area of cyclonic activity over the northern Pacific. The absence of a strong ridge extending from Canada towards Siberia and the persistence of the zonal circulation were the main factors which produced the generally mild winter across North America. Precipitation was less than normal over most of the United States of America except for the west and south-west. The heaviest precipitation here was associated with several late winter storms that crossed the Pacific in the strong westerlies at low latitudes. A strong flow from the Atlantic also brought mild weather, storminess and above-average rainfall to parts of western Europe, but the widespread blocking across northern Eurasia increased radiational cooling of air masses from Scandinavia eastwards and southwards. The westerlies were stronger than usual south of the Himalayas.

An extremely fast westerly flow persisted over the Pacific throughout the spring months (March to May), but at higher latitudes than in winter. An unusually strong and persistent ridge was centred over the Rocky Mountains. This swift westerly flow split, with one stream moving northwards and another southwards, passing through a broad trough across the southern United States. In the vicinity of the blocking zone over portions of the United States and the Canadian Great Plains, the dearth of storm systems meant dry weather and severe drought. Both April and May were among the driest months on record for parts of this region, while average spring temperatures were well above normal near and just to the west of the blocking ridge. The mid-latitude wave pattern from the Atlantic to eastern Asia was accentuated. Deep troughs over southern Europe, the western part of the Union of Soviet Socialist Republics and eastern Asia were associated with cold and sometimes wet conditions.

A long-wave circulation pattern across the northern hemisphere during the summer (June to August) meant spells of either warm and dry or cold and wet weather. The North American circulation was dominated by two persistent features: an anticyclone over the southern half of the continent, and a deep Arctic low. Precipitation totals were only between 25 and 50 per cent of normal over a large area of the American and Canadian plains, with temperatures averaging 2° to 4°C above normal. A notable break in the drought occurred on 9/10 August when Allen, one of the most intense Atlantic hurricanes on record, was steered westwards across the Atlantic and Caribbean into the Gulf of Mexico, south of the persistent and unusually strong subtropical high-pressure ridges that affected those areas most of the summer. The well-defined area of negative height anomalies covering western Europe in June and July was reflected at the surface by low temperatures and excessive rainfall. However, by August the area of negative height anomalies covered eastern Europe and European USSR, while the weather in western Europe improved considerably. The summer was relatively warm and dry in Scandinavia as a result of a small blocking situation, but it was cool and wet in European USSR. In July a significant area of positive anomalies formed over eastern Siberia and intensified in August. A deep trough west of Japan produced north-easterly winds across the Sea of Japan, making it one of the wettest and coolest summers on record.

The 700-mb westerlies again became stronger than normal at mid-latitudes over the Pacific during autumn (September to November), while a deep main trough developed south of the Aleutians, the subtropical ridge remaining stronger than normal to the south. Similar conditions existed over the Atlantic and Europe. Accentuated ridges associated with warmer than normal air were located over central Asia and western North America, and blocking waves frequently retrograded from the North Atlantic across Greenland and northern Canada to the Beaufort Sea. Rather colder than normal temperatures prevailed over Alaska, eastern North America and northern Europe, especially in November, when anomalies of -12°C occurred over the eastern Arctic Ocean. A rather mobile and highly variable pattern of large amplified troughs and ridges prevailed during the last month of 1980, with corresponding variations in the weather.

B. SOUTHERN HEMISPHERE

The year began with positive anomalies of the 500-mb geopotential height field extending in a broad band from South America, across the South Atlantic, and into the Indian Ocean to southern and western

* The material in this section was kindly provided by the World Meteorological Organization in advance of publication in the *WMO Bulletin* (vol. xxx, No. 3, July 1981). Meteorological services in Australia and the United States originally supplied most of the technical information included in the hemispheric reviews.

Australia. This general circulation feature was also evident during January over Antarctica, where it remained as a permanent feature for the first months of 1980. The negative height anomalies and increased cyclonicity which had characterized the southern Pacific Ocean through most of 1979 continued well into 1980. There was also a persistent area of negative anomalies south of the Great Australian Bight during the first part of the year. Its position farther south than normal in March helped to explain the severe drought that most of the southern half of Australia suffered. New Zealand experienced a number of storms in January and March, but in February the weather was much drier than it had been since June 1979.

The large area of negative geopotential anomalies over the South Pacific was maintained throughout the southern hemisphere during the autumn. A series of weak broad troughs developed off the coast of southern Africa at about 50°S, 115°E, while Antarctica was covered by an area of higher than normal geopotential. A blocking pattern became evident in the Tasman Sea in association with a positive anomaly at 45°S. Consequently, April and May were generally warm, dry and calm over New Zealand and the southern and eastern parts of Australia.

The positive anomaly pattern that became established over large areas of Antarctica at the beginning of the year weakened considerably in June. This was reflected once again by lower than normal surface temperatures. Above-normal geopotential was re-established in July and persisted until the end of the year. In August, dramatic temperature anomalies occurred, ranging from +6°C over the eastern half of Antarctica to -4°C over the western peninsula. A belt of positive height anomalies covered the eastern half of the southern hemisphere, with centres over the south-eastern Atlantic and the central Indian Ocean. Troughs were much weaker in June than in earlier months, the only exception being a broad trough over the central Pacific at 40°S, 140°W. A clearly defined three-wave pattern was established in July and continued into August and September. Troughs were positioned over the South Atlantic, the central Indian Ocean and the central Pacific, the latter being particularly strong. Ridging was also strong over the Australian continent. However, a belt of negative anomalies extending from the central Indian Ocean to the central Pacific gave rise to enhanced zonal flow across southern Australia. Above-normal ridging occurred over South America during August and September.

During the last four months of 1980, the ridge over the Australian continent moved out over the Tasman Sea. There were pronounced positive temperature anomalies during September and November over southern Australia and rainfall was below average. During November a weak trough developed to the east of New Zealand, producing weather that was wet (about 130 per cent of normal rainfall) and cool (1.9°C below normal). By December, a blocking pattern developed south of Tasmania and New Zealand. The strong ridge that had been evident south of southern Africa between July and September retrogressed to the South Atlantic. A series of troughs was apparent, located over the western Indian Ocean, the Australian Bight, the central Pacific and the central Atlantic.

II. SUMMARY OF TROPICAL CYCLONES

A. WESTERN NORTH PACIFIC TROPICAL CYCLONES

During 1980, the western North Pacific experienced the second consecutive year of below-normal tropical cyclone activity (see table 1). There were 28 tropical cyclones both in 1979 and in 1980, as compared to the average annual total of about 33. During 1980, four significant tropical cyclones failed to develop beyond the tropical depression stage, and nine tropical storms failed to reach typhoon intensity. Of the 15 tropical cyclones that developed to typhoon intensity, only two reached the 130 kn (67 m/sec) intensity required for classification as super typhoons. Tropical cyclones reaching or exceeding tropical storm intensity are assigned names in alphabetical order from an internationally recognized list of alternating male/female names. Different lists of alternating male/female names are used for eastern and central North Pacific and North Atlantic cyclones. The maximum surface winds in knots and minimum observed sea level pressure in millibars were obtained for each tropical cyclone from the best estimates based on all available data. The distance travelled, in nautical miles, was calculated from the official best track of JTWC at Guam.

Table 2 provides further information on the monthly distribution of tropical cyclones and statistics on TCFAs and Warnings. From 1979 to 1980, the number of warning days decreased from 149 to 128.

Figures 1a through 1d show the best tracks of tropical cyclones in the western North Pacific throughout 1980.

B. NORTH INDIAN OCEAN TROPICAL CYCLONES

During 1980, there was a notable lack of significant tropical cyclone activity in the North Indian Ocean area (see table 1). Two tropical cyclones developed near the end of the year: one in the Arabian Sea (TC 23-80), and one that began in the Bay of Bengal (TC 27-80) and tracked south of India into the Arabian Sea. This was a dramatic decrease from the 1979 total of seven cyclones observed in the two areas.

Table 1. Significant tropical cyclones in 1980 in the western North Pacific Ocean and North Indian Ocean

Cyclone	Type[a/]	Name	Period of warning	Calendar days of warning	Maximum surface wind (knots)	Minimum observed sea-level pressure (millibars)	Number of warnings	Distance travelled (nautical miles)
			Western North Pacific Ocean					
01	TD	TD 01	20 Mar.-24 Mar.	5	30	1 000	17	2 439
02	TS	Carmen	5 Apr.-8 Apr.	4	60	980	9	1 179
03	TY	Dom	9 May-19 May	11	90	956	42	1 938
04	TY	Ellen	13 May-21 May	9	110	931	34	2 423
05	TS	Forrest	20 May-26 May	7	55	990	26	2 451
06	TS	Georgia	21 May-24 May	4	55	985	12	993
07	TS	Herbert	24 June-28 June	5	50	980	15	2 521
08	TS	Ida	6 July-11 July	6	60	980	23	1 527
09	TY	Joe	17 July-23 July	7	105	940	25	2 541
10	TD	TD 10	17 July-19 July	3	30	1 000	7	1 007
11	ST	Kim	20 July-27 July	8	130	908	29	2 661
12	TY	Lex	29 July-7 Aug.	10	80	962	36	1 810
13	TY	Marge	8 Aug.-15 Aug.	8	110	944	31	1 980
14	TD	TD 14	15 Aug.-16 Aug.	2	20	1 003	7	229
15	TY	Norris	24 Aug.-28 Aug.	5	90	950	20	1 710
16	TD	TD 16	4 Sept.-6 Sept.	3	25	1 002	8	776
17	TY	Orchid	7 Sept.-11 Sept.	5	85	958	19	2 043
18	TY	Ruth	14 Sept.-16 Sept.	3	65	975	13	60
19	TY	Percy	14 Sept.-19 Sept.	6	125	919	20	1 260
20	TY	Sperry	15 Sept.-20 Sept.	6	65	987	22	2 624
21	TS	Thelma	26 Sept.-30 Sept.	5	55	982	16	1 681
22	TY	Vernon	27 Sept.-3 Oct.	7	105	935	25	2 141
23	ST	Wynne	4 Oct.-14 Oct.	11	150	890	44	3 728
24	TS	Alex	12 Oct.-14 Oct.	3	35	999	8	1 844
25	TY	Betty	29 Oct.-7 Nov.	10	120	928	39	3 228
26	TS	Cary	29 Oct.-1 Nov.	4	40	998	14	1 068
27	TY	Dinah	21 Nov.-25 Nov.	5	100	941	17	3 530
28	TS	Ed	16 Dec.-21 Dec.	6	50	988	20	815
			Total	128[b/]			598	
			North Indian Ocean					
	TC	23-80	17 Nov.-19 Nov.	3	35	995	8	940
	TC	27-80	16 Dec.-17 Dec.	2	35	996	6	2 122
			Total	5			14	

Source: Joint Typhoon Warning Center, United States Naval Oceanography Command Center, Guam, Mariana Islands; 1980 Annual Tropical Cyclone Report (Guam, Mariana Islands, 1981).

Notes: a/ TD = tropical depression; TS = tropical storm; TY = typhoon; ST = super typhoon; TC = tropical cyclone.

b/ Overlapping days included only once in sum.

Table 2. Significant tropical cyclone statistics for 1980 in the western North Pacific Ocean

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average (1959-1979)
Tropical depressions	0	0	1	0	0	0	1	1	1	0	0	0	4	4.8
Tropical storms	0	0	0	1	2	1	1	0	1	2	0	1	9	10.0
Typhoons	0	0	0	0	2	0	3	2	5	2	1	0	15	17.8
All cyclones	0	0	1	1	4	1	5	3	7	4	1	1	28	32.6
Average (1959-1979)	0.6	0.4	0.6	0.9	1.4	2.0	5.2	6.7	6.0	4.7	2.7	1.4	32.6	

Formation alerts: 28 of the 37 (76 per cent) formation alert events developed into tropical cyclones. Tropical cyclone formation alerts were issued for all significant tropical cyclones which developed during 1980.

Warnings: Number of warning days: 128
Number of warning days with two cyclones: 37
number of warning days with three or more cyclones: 3

Source: Same as table 1.

Table 3. Significant tropical cyclone statistics for 1980 in the North Indian Ocean

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
All cyclones	0	0	0	0	0	0	0	0	0	0	1	1	2
Average[a/] (1971-1979)	0.1	0	0	0.3	0.5	0.4	0	0	0.5	0.8	1.5	0.3	4.4

Formation alerts: Two of the seven (28 per cent) formation alert events developed into number cyclones.

Warnings: Number of warning days: 5
Number of warning days with two cyclones: 0
Number of warning days with three or more cyclones: 0

Source: Same as table 1.

Note: a/ From 1971 through 1979, only Bay of Bengal cyclones were considered; the JTWC area of responsibility was extended in 1975 to include Arabian Sea cyclones.

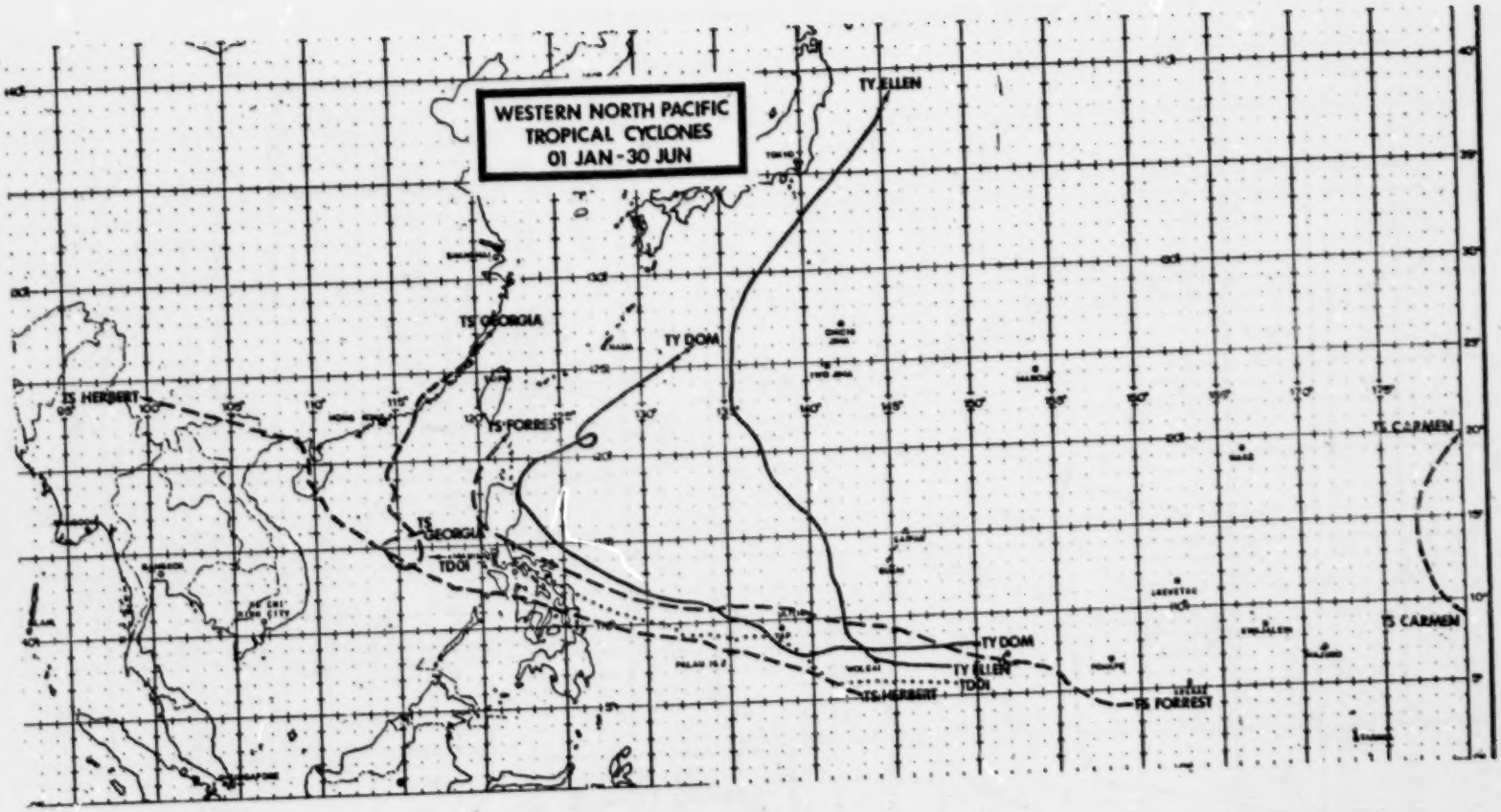

Figure 1a. Tropical cyclones in the western North Pacific, 1980
(1 January-30 June)

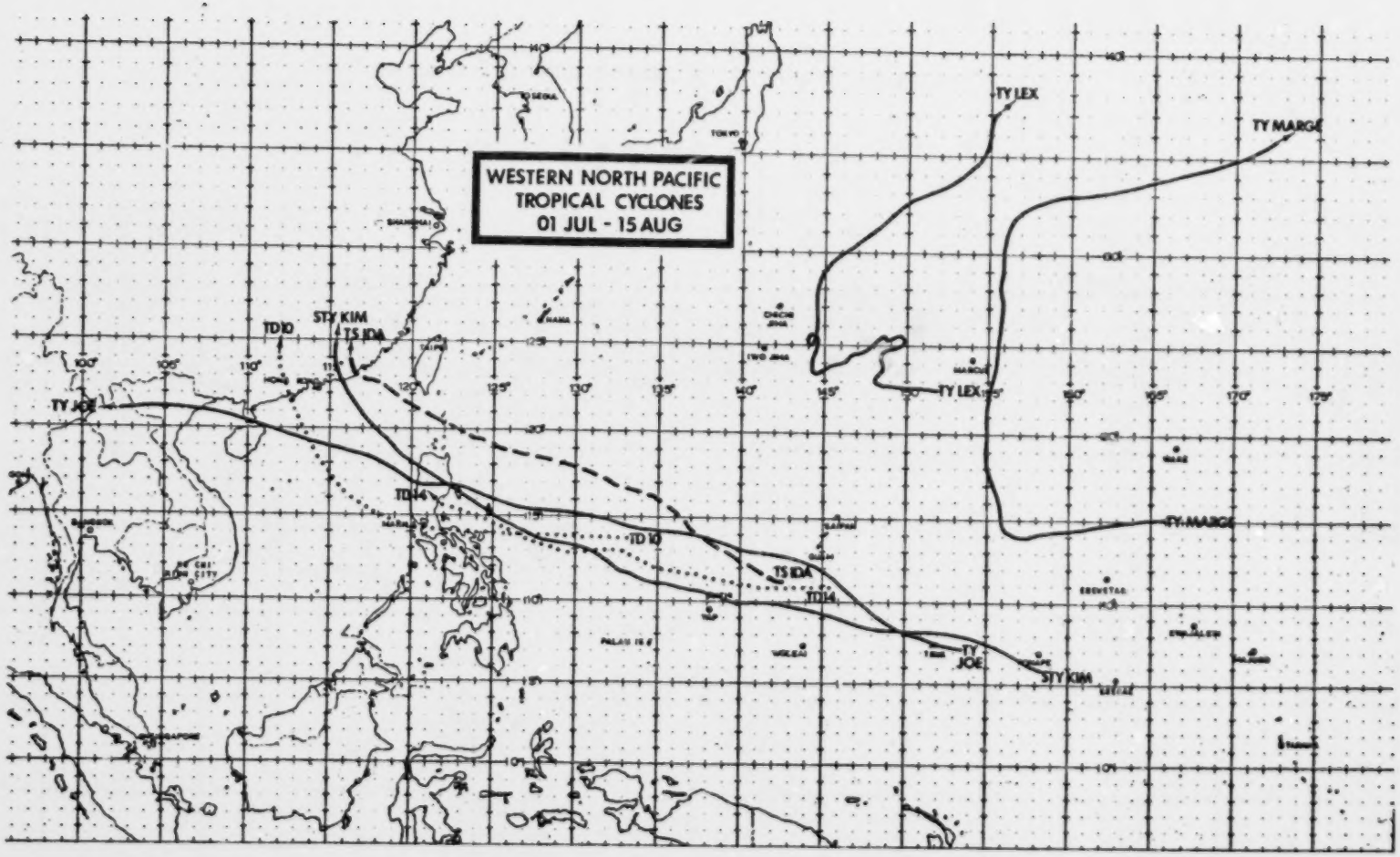

Figure 1b. Tropical cyclones in the western North Pacific, 1980
(1 July-15 August)

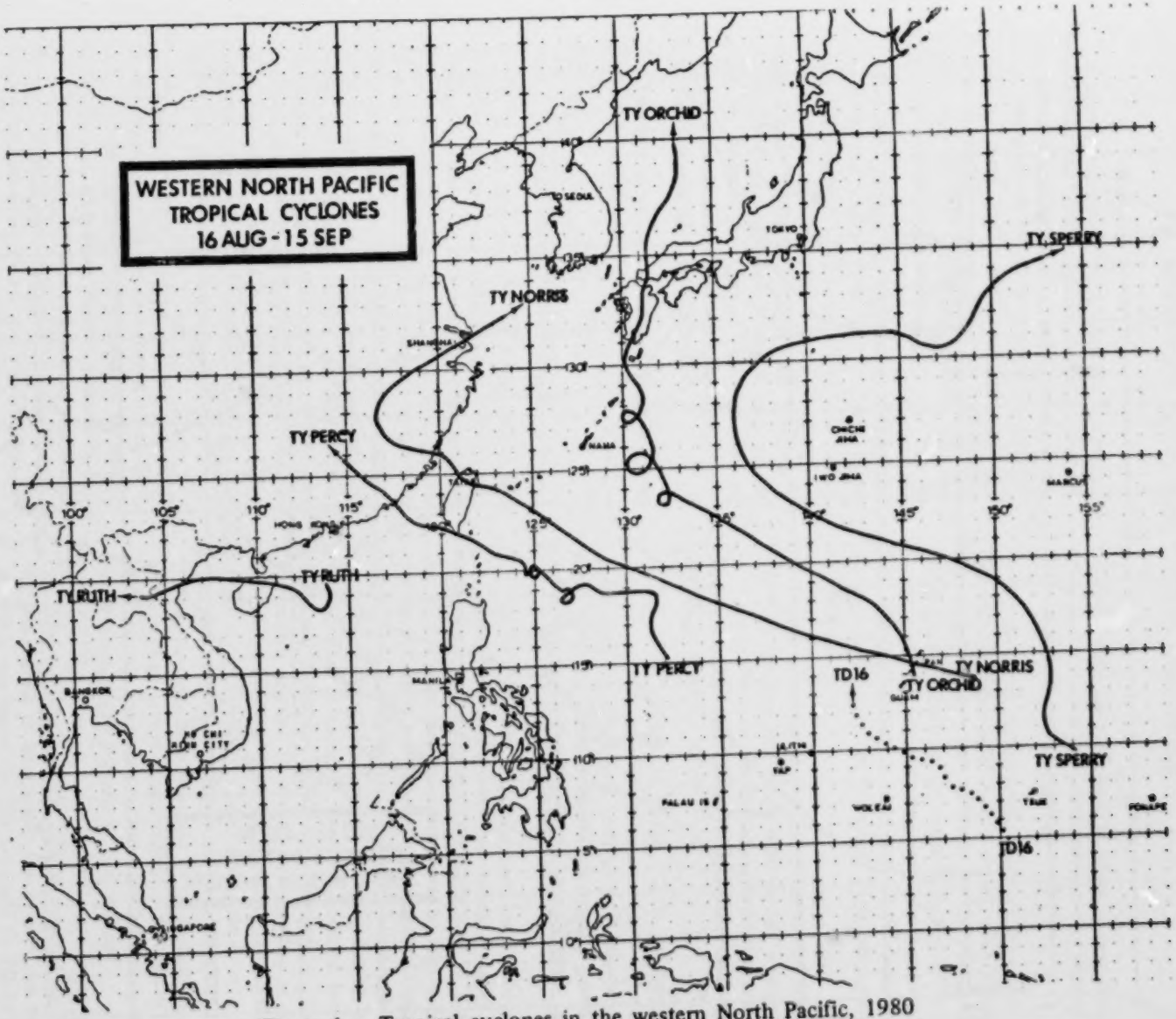

Figure 1c. Tropical cyclones in the western North Pacific, 1980
(16 August-15 September)

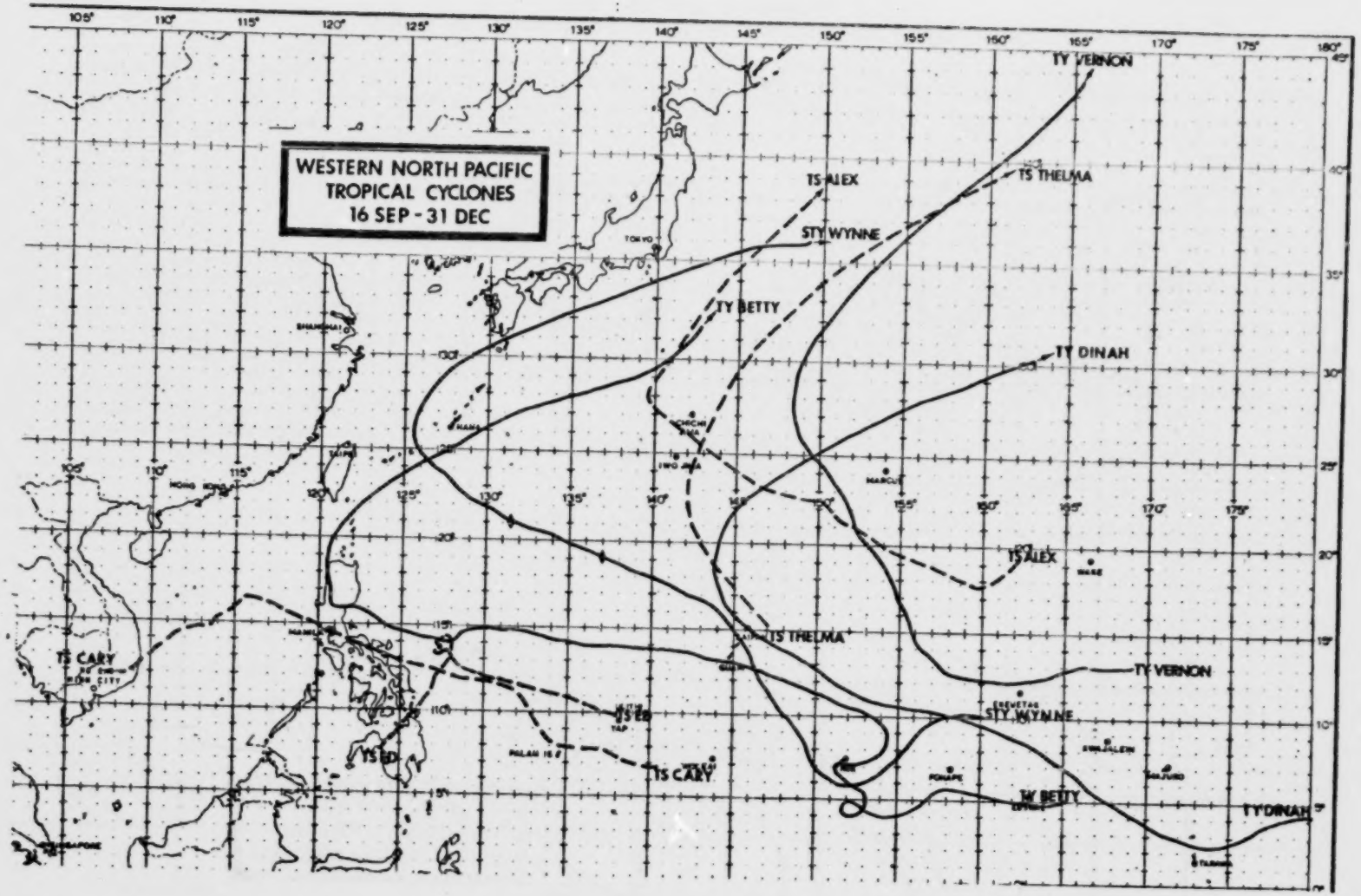

Figure 1d. Tropical cyclones in the western North Pacific, 1980
(16 September-31 December)

III. INDIVIDUAL NARRATIVES OF MAJOR TROPICAL STORMS AFFECTING ASIAN AND PACIFIC COUNTRIES

Narratives of major tropical storms in the western North Pacific and North Indian oceans during 1980 have been extracted from the *1980 Annual Tropical Cyclone Report* and appear in the following pages. The selection consists of those storms which inflicted significant damage in ESCAP member countries, and includes events reported by individual countries in the subsequent section of this volume.

The *1980 Annual Tropical Cyclone Report* was prepared by the staff of JTWC of the United States Naval Oceanography Command Center at Guam, Mariana Islands. Annual reports in the series (previously named *Annual Typhoon Reports*) date from 1959, the year JTWC was established. Copies of reports in the series are available on request from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, United States.

The times given in the text are Zulu (Z) time (Greenwich mean time).

A. TROPICAL DEPRESSION 01

TD 01 was first detected as an area of increased convective activity about 500 naut mi (926 km) south-southeast of Guam on 16 March. During the early part of the year, intense convective activity is usually located south of the equator. March is the start of the transition period when the equatorial trough begins to migrate slowly northward. During this period, the equatorial trough can occasionally extend into the northern hemisphere. This extension, however, is normally short-lived because the south-west monsoon has yet to become fully established. Post-analysis indicates that TD 01 developed from a temporary extension of the equatorial trough into the northern hemisphere.

The first aircraft reconnaissance mission into TD 01 on the morning of 18 March reported 15 to 20 kn (8 to 10 m/sec) surface winds, primarily in the northern semicircle, and a minimum sea-level pressure of 1,005 mb. On the basis of this information and satellite imagery, which showed improved upper-level outflow in the south-east quadrant, a tropical cyclone formation alert (TCFA) was issued at 180300Z.

The tropical disturbance was monitored closely for the next 48 hours. The first reconnaissance mission also reported a 60 naut mi (111 km) displacement between the surface centre and the 1,500 ft (457 m) centre. Subsequent missions discovered a similar displacement between the surface and 700-mb centre. This was consistent with the synoptic data which showed that strong mid- to upper-level south-easterlies were causing TD 01 to tilt with height toward the north-west.

By 20 March, surface winds in the southern semicircle had increased to 20 kn (10 m/sec), while 30 kn (15 m/sec) winds were observed in the northern semicircle. The circulation was better defined on satellite imagery, and the minimum observed sea-level pressure had decreased to 1,000.7 mb. Continued development was expected and the first warning on TD 01 was issued at 200600Z.

Taking into consideration the strong vertical wind shear and the fact that March is historically a month of minimum typhoon development, TD 01 was never forecast to reach more than a minimum tropical storm strength of 40 kn (21 m/sec).

From 20 through 24 March, TD 01 followed a climatological west-northwest track toward Luzon, occasionally showing speed changes as it responded to a series of mid-level short-wave troughs moving eastward across the Pacific from the Asian mainland.

As TD 01 approached south-eastern Luzon, it began to interact both with a shear line extending toward it from the north-east and a building high-pressure ridge north of Luzon. The net result was a flare-up in the convective activity and an increase in surface wind speed north of the surface centre. Although two land stations reported 40 kn (21 m/sec) winds during landfall on Luzon, sea-level pressures were not observed below 1,007 mb. Considering the effects of topography, 30 kn (15 m/sec) appears to be the best estimate of the intensity of TD 01 at that time. North-easterly winds of 25 to 40 kn (13 to 21 m/sec) were present north of TD 01. These strong winds were being enhanced by TD 01, but were more the result of the building high-pressure ridge off the Asian mainland. An extratropical wind warning was therefore issued for the area by the Naval Oceanography Command Center at Guam.

After making landfall, TD 01 tracked slowly westward south of Manila into the South China Sea. A TCFA was issued for the remnants of TD 01 at 260615Z, when improved organization of the cloud pattern suggested that regeneration might occur. The disturbance was watched for three more days, but ship reports showed nothing more than a weak wave in the east-northeasterly flow, and the system dissipated rapidly after moving ashore on the Vietnamese coast near Ho Chi Minh City.

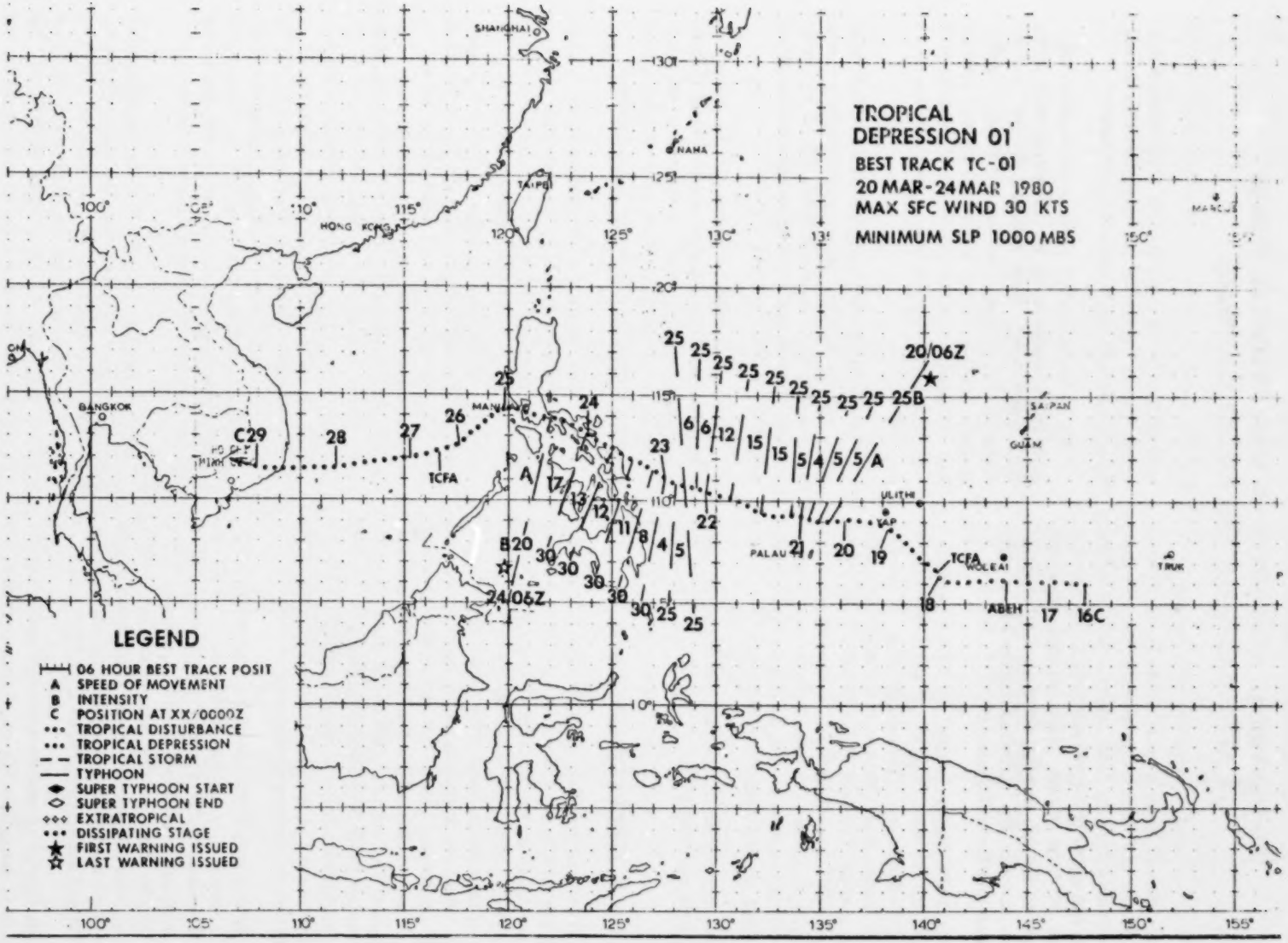

Figure 2. Tropical Depression 01, best track

B. TYPHOON DOM (03)

Dom was the first tropical cyclone that developed to typhoon intensity in the western North Pacific in 1980. Dom had several features of interest: a pronounced tilt in the vertical axis during the developing stages and the execution of a rare anticyclonic loop in the later stages of its existence.

Satellite imagery showed a weak disturbance which first appeared along the near-equatorial trough on 5 May. The disturbance showed no significant development as it tracked across the Caroline Islands during the following three days. The first investigation by reconnaissance aircraft was scheduled on 8 May, when a significant increase in convective activity was noted. The weak circulation located by the aircraft caused JTWC to issue a TCFA for an area south of Guam. By 9 May, satellite imagery indicated strong outflow on the west side of the circulation and increased organization of convective cloud elements became evident as the disturbance continued to develop. As the circulation became more organized, reconnaissance aircraft observed an increase in the surrounding surface winds. The first warning on TD 03 was issued at 090000Z.

Little change in intensity occurred during the next two days, during which time the 700-mb circulation was displaced by as much as 77 naut mi (143 km) west-southwest of the surface centre. This displacement was indicative of marked vertical shear caused by strong mid- to upper-level easterly flow.

Vertical shear remained strong during Dom's early stages of development as it moved westward, steered by strong mid- to upper-level easterlies along the southern periphery of the mid-level subtropical ridge axis. On 10 May, a mid-tropospheric low-pressure centre developed over the Asian mainland, causing the ridge to recede eastward. This created a weakness in the ridge near the Philippines, allowing Dom to track west-northwestward away from the strong mid- to upper-level easterlies. With the decrease in vertical wind shear, Dom's axis became more vertical and development proceeded. Dom reached tropical storm intensity at 101800Z as an anticyclone, with outflow in all quadrants developed at upper levels.

A large area of low-level convergence formed to the north-east of Dom as evidenced by convective activity shown by satellite imagery on 11 May. This area of convection dissipated as an induced ridge formed between Dom and a circulation to the south-east of Guam, which would later develop into Typhoon Ellen. Dom attained typhoon intensity at 120600Z. When Dom intensified to 90 kn (46 m/sec), it had a large eye 30 naut mi (56 km) in diameter and its speed of movement decreased markedly as it moved away from the strong mid- to upper-level easterly steering flow. Dom became virtually stationary as it drifted slowly toward Luzon, with weakening commencing as a result of the decreased moisture content of the air being drawn into Dom's circulation across the mountainous terrain of Luzon. By 141200Z, Dom had weakened to tropical storm intensity and was tracking northward at 2 kn (1 m/sec), showing indications of impending recurvature.

Dom unexpectedly regained typhoon strength 24 hours after recurvature. Reintensification was made possible by a lessening of the land effect and energy provided by a tongue of warm water extending north of Luzon. Dom then tracked north-eastward south of the area of maximum sea-surface temperature (SST). A later SST analysis showed the decrease in SST which is normally observed after the passage of a tropical cyclone. This decrease in SST is caused primarily by evaporative cooling and the mixing of surface water with cooler subsurface water and, to a lesser extent, by the addition of rain water and the decrease in solar radiation reaching the surface. Dom's final decrease to tropical storm intensity was due to the shearing effect of strong upper-tropospheric westerlies and strong low-level easterlies. The upper-level centre continued to track eastward, whereas the surface circulation began a rare anticyclonic loop as it tracked westward under the influence of the low-level easterly flow. At 190000Z, JTWC issued the final warning on Dom, although post-analysis indicated it ceased to exist as a significant tropical cyclone on 18 May.

Triggered by a mid-tropospheric trough which entered the South China Sea, an extratropical surface low-pressure system formed south of Japan at 200000 Z, with the associated frontal boundary extending to the south-west of Okinawa. At this time, Typhoon Ellen was 600 naut mi (1,113 km) east-northeast of the remnants of Dom and Typhoon Ellen accelerated toward the extratropical low along the east side of the frontal boundary. By 211200Z, the three systems had merged to form an intensifying mid-latitude storm over the east coast of central Honshu, Japan. This deepening mid-latitude storm tracked north-eastward along the northern periphery of the mid-Pacific ridge.

C. TYPHOON ELLEN (04)

Typhoon Ellen developed in an active, near-equatorial trough west of the Truk Islands on 11 May 1980. Strong upper-level divergence over the Caroline Islands and a weak 500-mb steering current, produced by a northward adjustment of the 500-mb ridge axis to 25°N, provided an excellent environment for tropical cyclone development. Ellen was an interesting tropical cyclone from several viewpoints. During its existence, Ellen underwent rapid initial development, abruptly changed track at a low latitude, and followed a slow oscillatory motion for an 18-hour period.

Ellen's initial tropical disturbance became evident on satellite imagery between 111200Z and 120000Z. However, a TCFA was not issued at that time because

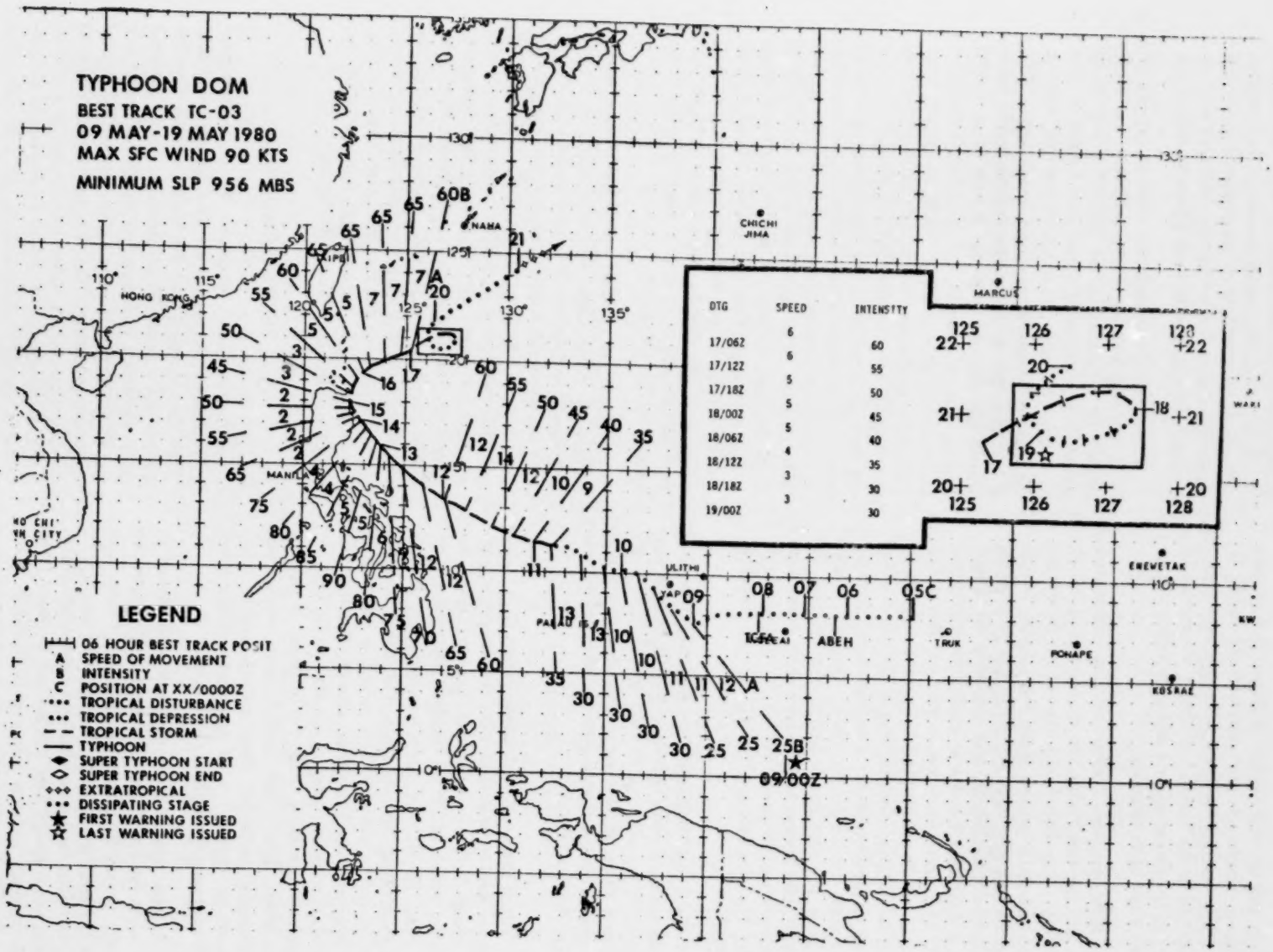

Figure 3. Typhoon Dom, best track

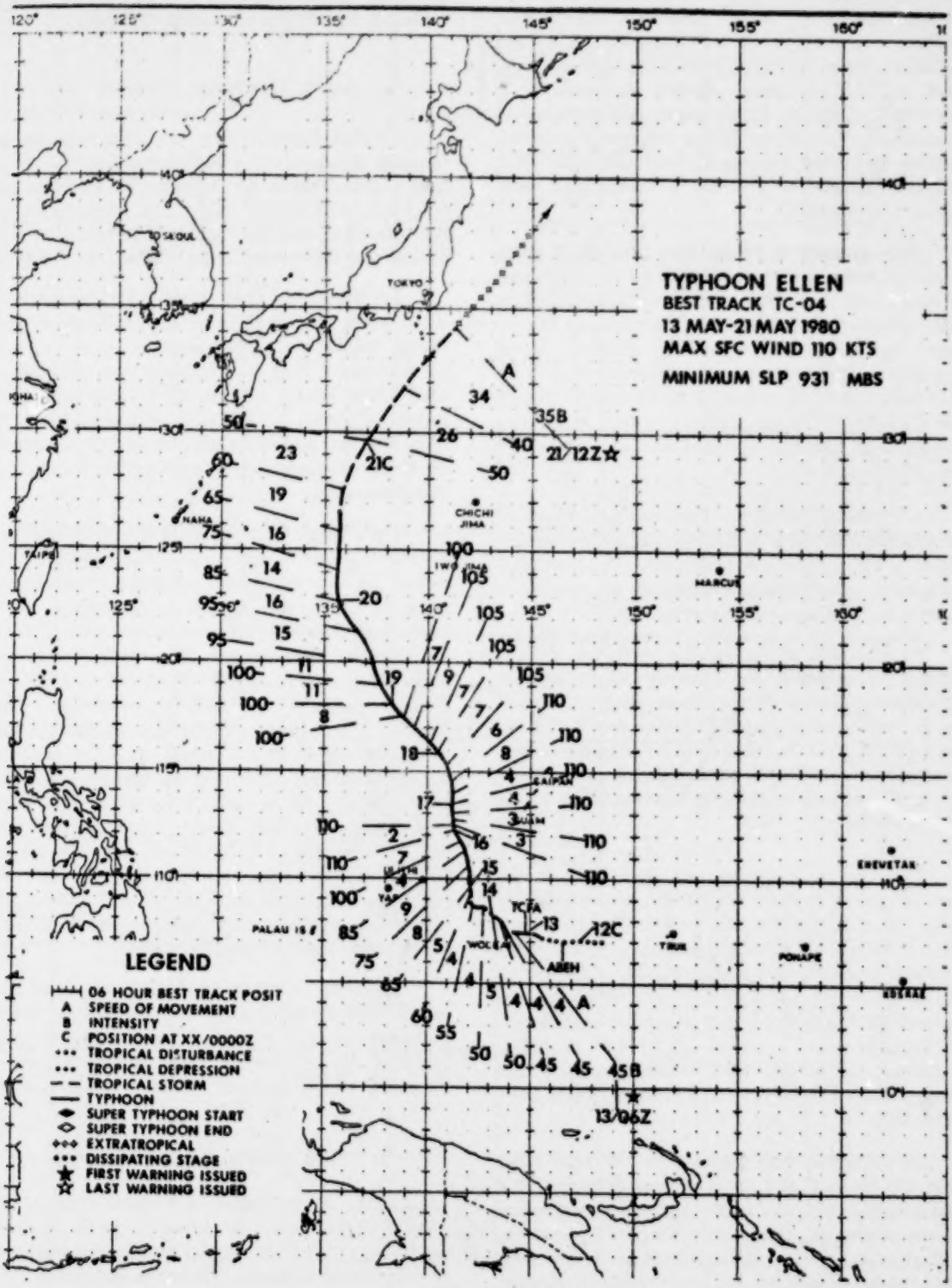

Figure 4. Typhoon Ellen, best track

120000Z synoptic data did not indicate a well-defined surface circulation with lowering surface pressures. A weakening of the satellite signature during the next 12 hours supported this decision. Between 121200Z and 121600Z, Ellen's satellite signature improved markedly and a TCFA was issued. Aircraft reconnaissance at 130422Z confirmed Ellen's rapid development and estimated 45 to 50 kn (23 to 26 m/sec) maximum surface winds. The first warning was issued at 130600Z. Post-analysis indicates that Ellen reached tropical storm strength at 121800Z.

Ellen appeared to be following Dom's track across the Philippine Sea as it tracked initially west over Woleai Atoll and then west-northwestward toward Ulithi Atoll. On 15 May, Ellen abruptly turned to the north and headed for Japan. By 150000Z, it was tracking north-northwestward at approximately 8 kn (15 km/h) and had intensified to 65 kn (33 m/sec). At 170000Z, Ellen passed 220 naut mi (407 km) west of Guam, with maximum sustained surface winds of 110 kn (57 m/sec).

After its abrupt turn, Typhoon Ellen's surface circulation followed a pronounced oscillatory motion about a basic north-northwest track. The short-term oscillations were difficult to interpret and thus made forecasting Ellen's movement very difficult.

As Ellen was undergoing this oscillatory motion, aircraft reconnaissance also observed that the location of minimum sea-level pressure appeared to rotate close to the wall cloud in a highly elliptical eye. During the same period, Ellen deepened to its lowest minimum sea-level pressure of 931 mb and intensified an additional 45 kn (23 m/sec), reaching its maximum intensity of 110 kn (57 m/sec).

This oscillatory motion and uncertainty in the position and strength of the 500-mb subtropical ridge axis created a significant forecast problem. Forecasts of early recurvature to the north-east did not materialize as Ellen continued on a north-northwest track toward Japan. Once north of the ridge axis, Ellen recurved between 25°N and 30°N and accelerated north-eastward at forward speeds in excess of 30 kn (56 km/h). Following recurvature, Ellen weakened rapidly and merged with an extratropical low-pressure system south of Honshu.

Ellen's actual track passed closer to Japan than originally forecast, as a result of rapid deepening of a mid-latitude trough over Japan and rapid intensification of the subtropical ridge east of Japan. In response, 500-mb winds south of Japan backed in direction and strengthened, causing Ellen to accelerate north-eastward and pass 120 naut mi (222 km) east of Yokosuka Naval Station, Japan. Department of Defense resources in Japan reported no major damage, and Yokosuka only reported 20 to 25 kn (10 to 13 m/sec) sustained winds during the passage of Ellen. The flooding reported in Kyushu and Shikoku resulted from heavy rain produced by the extratropical low-pressure system which eventually merged with Ellen south of Honshu.

D. TROPICAL STORM FORREST (05)

Tropical Storm Forrest was influenced by an unusually large and strong mid-tropospheric ridge which built westward across the Philippine Sea following the recurvature of Typhoon Ellen. This ridge dominated the entire north-western Pacific and affected Forrest's direction of movement, forward speed, and intensity.

For the major part of its track, TS Forrest skirted the southern periphery of the large subtropical ridge. During the month of May, cyclones typically track north-westward over the Philippine Sea. However, a nearly zonal 500-mb flow prevailed during this period and forced Forrest to track nearly due west. This steady zonal flow also pushed Forrest forward at speeds reaching 18 kn (33 km/h), which is three times the climatological mean speed.

The strength of the subtropical ridge also affected Forrest's intensity. The subtropical ridge raised environmental pressures throughout the north-western Pacific north of TS Forrest. Aircraft reconnaissance consistently observed winds in TS Forrest that were 10 to 15 kn (5 to 8 m/sec) stronger than would be expected from its minimum sea-level pressure of 990 mb and given the Atkinson and Holliday[1] pressure/wind relationship. The Atkinson and Holliday relationship indicates that the 55 kt (28 m/sec) maximum sustained winds observed in TS Forrest are typically associated with tropical cyclones having a 983-mb minimum sea-level pressure. Aircraft reconnaissance also observed that Forrest tilted south-southwest from the surface to 700 mb. The surface and 700-mb centres were displaced as much as 35 naut mi (65 km) at times, apparently in response to upper-level north-east flow which existed over TS Forrest.

Following landfall on Luzon, TS Forrest weakened rapidly while passing approximately 40 naut mi (74 km) north-east of Clark Air Base. Highest observed wind speeds at this location associated with the passage of TS Forrest were in the 10 to 15 kn (5 to 8 m/sec) range.

E. TROPICAL STORM GEORGIA (06)

Tropical Storm Georgia is a classic example of a tropical cyclone which developed in the South China Sea during the transition period between the north-east and south-west monsoon. "Monsoon depressions" are

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[1] G.D. Atkinson and C.R. Holliday, "Tropical cyclone minimum sea-level pressure–maximum sustained wind relationship for western North Pacific", *Monthly Weather Review*, vol. 105, No. 4 (1977), pp. 421-427.

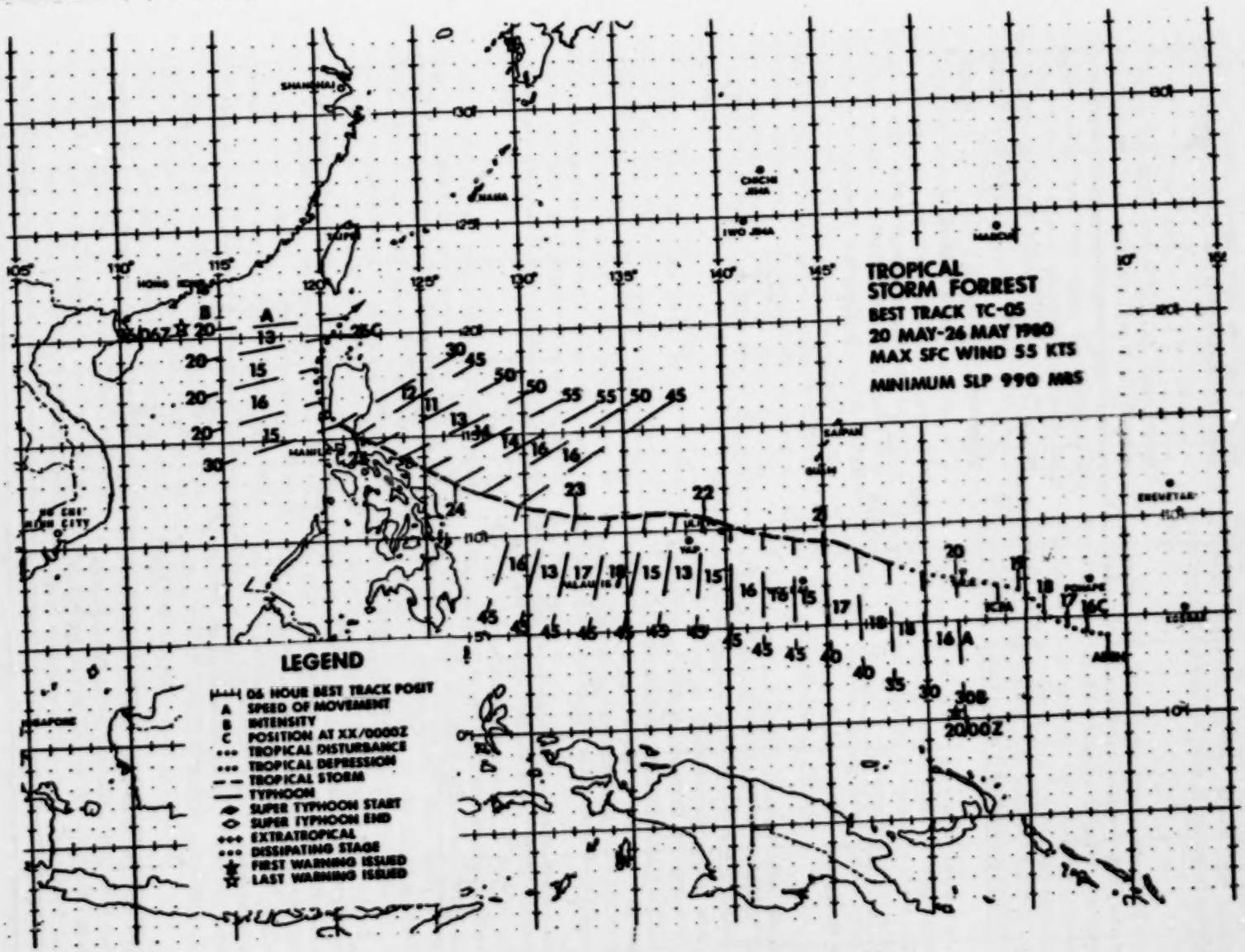

Figure 5. Tropical Storm Forest, best track

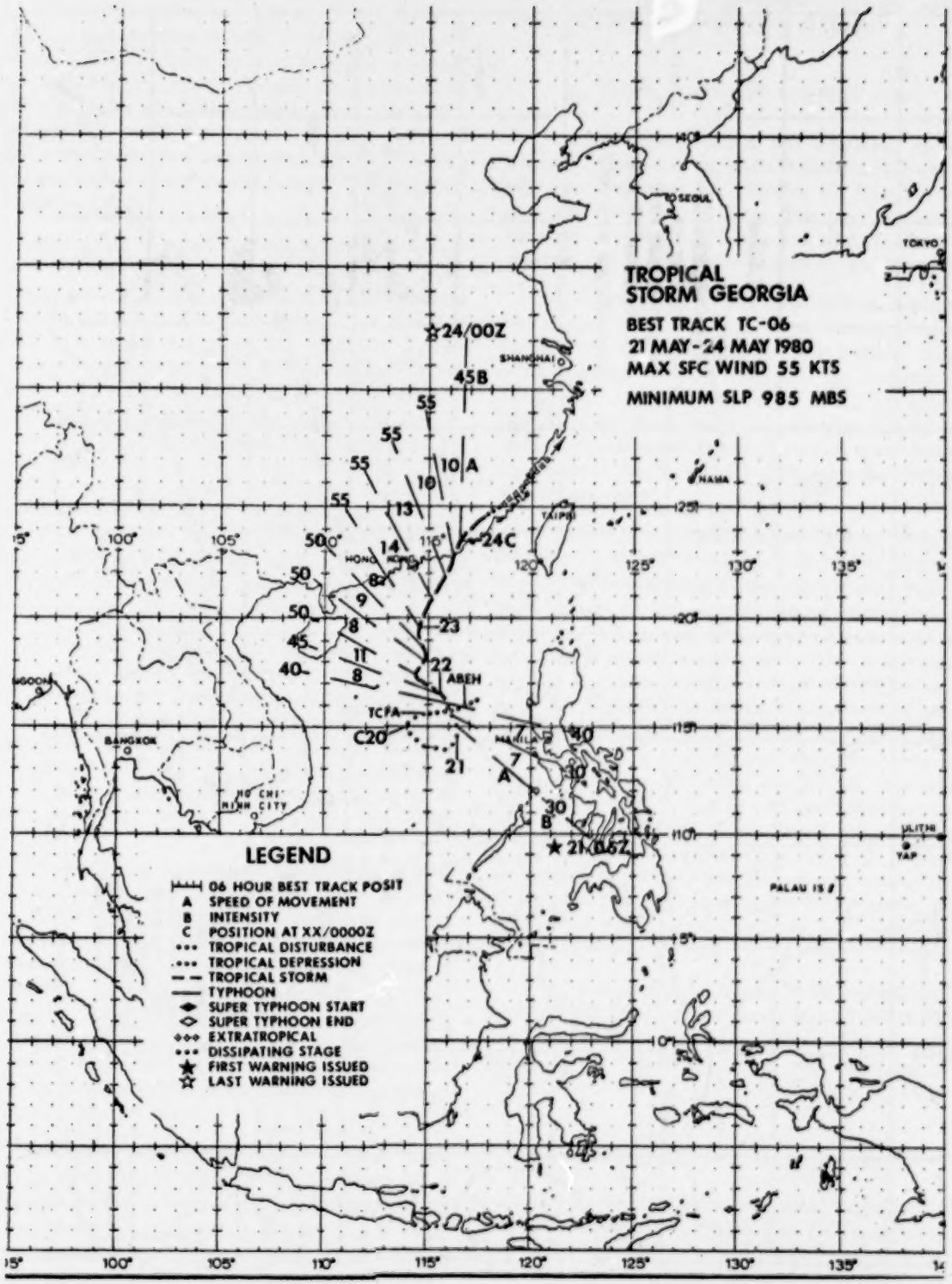

Figure 6. Tropical Storm Georgia, best track

often short-lived, difficult to locate with precision, and usually have broad but relatively weak surface circulation patterns. Georgia might well have reached typhoon strength if it had been able to remain over open water.

During the latter part of May, an active surface trough extended from near Iwo Jima south-westward into the South China Sea. Embedded in this trough were Typhoon Ellen, near Iwo Jima, the remnants of Typhoon Dom (an exposed low-level circulation), and the weak tropical disturbance which would become Tropical Storm Georgia.

Synoptic data first indicated possible tropical cyclone development in the South China Sea on 19 May. Although the satellite signature was poor, the synoptic data showed a surface circulation with a significant pressure drop near the centre. Based on these data, a TCFA was issued at 191341Z. Surface streamline analysis at 200000Z illustrated well-defined surface circulation. Corresponding satellite imagery at about the same time still showed a lack of convective organization. The depression finally began to show significant development, and the first warning on TD 06 was issued at 210600Z.

JTWC forecasters relied heavily on the forecast aids which were consistent in indicating northward movement with recurvature near the coast of China. Southerly 500-mb steering winds also supported northward movement. Increase in surface inflow and the resulting increase in organized convective activity occurred shortly after Georgia reached tropical storm strength.

Only two aircraft reconnaissance missions were flown on Tropical Storm Georgia. The first mission observed a minimum sea-level pressure of 986 mb and surface winds of 50 kn (25 m/sec). The second mission could not provide a centre fix because of restricted air space, as a result of Georgia's proximity to both China and Hai-nan Island. Two ships, the "Clara Maersk" and the "Chevalier Paul", reported winds of 50 kn (26 m/sec) and 54 kn (28 m/sec), respectively. These observations support the best track estimated maximum intensity of 55 kn (28 m/sec).

After making landfall near Shan-tou, Georgia traveled north-northeastward, about 20 naut mi (37 km) inland from the coast, eventually passing north of Chin-men-tao, which reported winds of 44 kn (23 m/sec) with gusts to 60 kn (31 m/sec). Rapid weakening occurred thereafter as Georgia was absorbed into an extratropical low-pressure system that was moving over the East China Sea from the Asian mainland.

F. TROPICAL STORM HERBERT (07)

A broad equatorial trough existed on 18 June, stretching from the Philippines to the eastern Caroline Islands along 5°N. Although synoptic data suggested several circulations along the trough axis, satellite imagery during the following 48 hours indicated increased convective activity around the eastern periphery of the trough as a result of convergent easterly flow.

At 201200Z, increased convection was noted near the primary surface circulation east of the Palau Islands. By 211200Z, satellite imagery indicated improved organization, with synoptic data revealing increased south-west gradient level inflow and 20 to 25 kn (11 to 13 m/sec) wind reports from ships north-east of the depression. As a result, a TCFA was issued at 211800Z.

The depression moved west-northwestward toward Leyte in the Philippines on 22 June. The mountainous island chain was expected to prevent further development and the TCFA was cancelled at 221800Z. However, the potential for significant tropical cyclone development was expected to improve once again as the depression entered the South China Sea.

Thus, with the depression located south of Mindoro and moving west-northwestward, a formation alert was reissued at 240000Z. Aircraft reconnaissance at 240717Z located a circulation centre just west of Busuanga Island, with surface winds estimated at 40 kn (21 m/sec) and a minimum sea-level pressure of 996 mb. Based on the aircraft data and evidence of increased convective activity on satellite imagery, the first warning on Tropical Storm Herbert was issued at 241200Z.

In the South China Sea, Herbert tracked north-westward toward Hai-nan Island while intensifying slowly. A maximum intensity of 50 kn (26 m/sec) was attained at 250600Z and was sustained for the next 24 hours as Herbert passed 15 naut mi (28 km) south-west of the Paracel Islands. Peak winds of 46 kn (24 m/sec) were reported by the islands at 260000Z. Landfall on Hai-nan occurred near 261800Z, with maximum sustained winds of 45 kn (23 m/sec). Over Hai-nan, Herbert tracked around the western face of Wu Chih Sham Mountain and exited due north into the Gulf of Tonkin. A north-northwest track over the Gulf of Tonkin ended with landfall south of Chin-hsien, China, at 280300Z with 45 kn (23 m/sec) intensity, as verified by land station report. Once over southern China, Herbert weakened quickly and dissipated as a significant tropical cyclone by 290000Z.

A strong mid-level ridge extending from southern China eastward across the Pacific along 24°N provided the steering flow as Herbert tracked steadily along the southern periphery of the ridge. The 500-mb analyses on 25 and 26 June showed that the ridge extended westward to near 108°E just west of Hai-nan Island. Thus, a turn toward the north-east was expected following landfall over southern China. However, the 270000Z, 500-mb analysis revealed that the ridge actually built westward across southern China, resulting

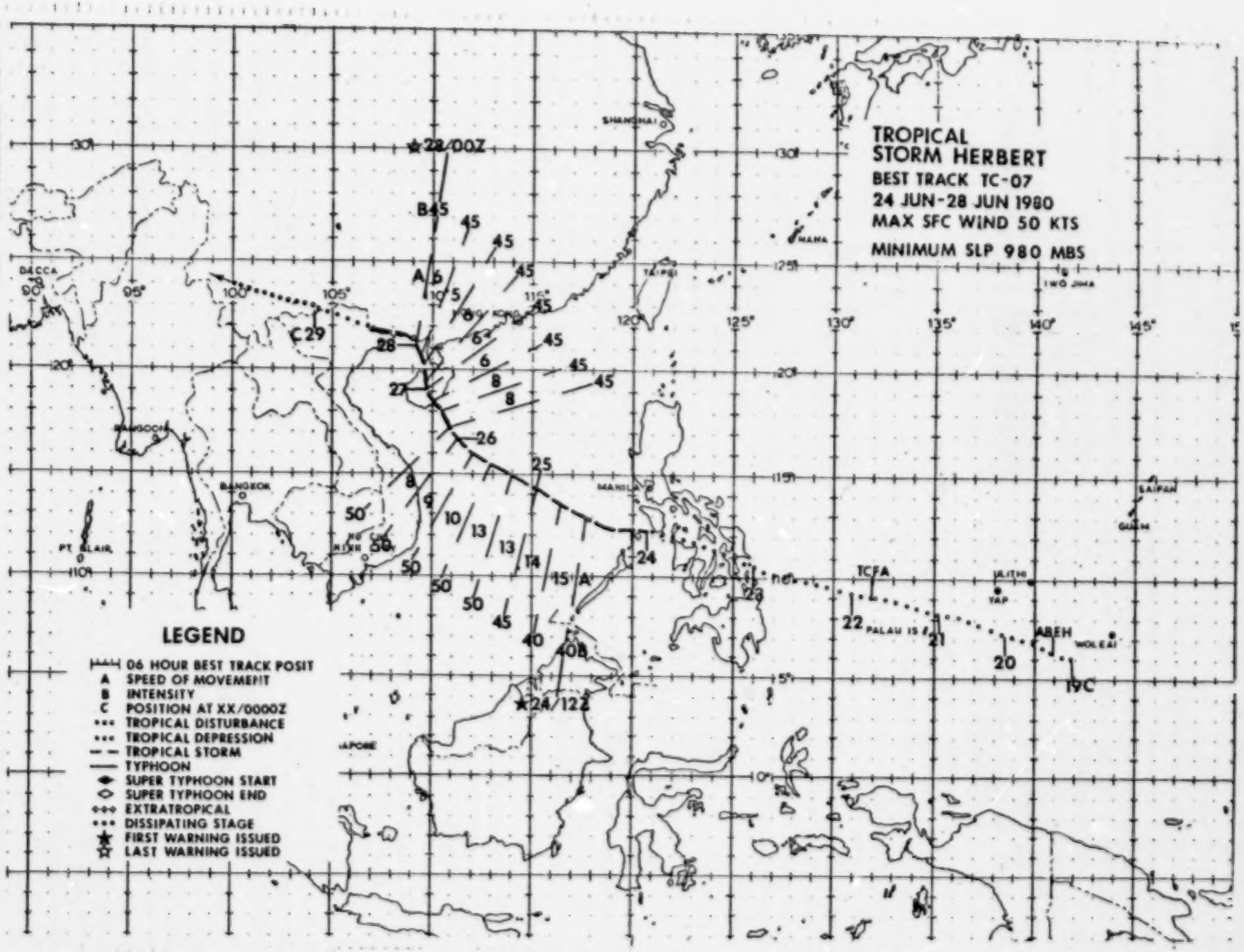

Figure 7. Tropical Storm Herbert, best track

in Herbert's westward track during his dissipation stage following landfall.

The definitive mid-level synoptic pattern and steering flow provided JTWC with good warning continuity and resulted in excellent forecast vector errors of 77 naut mi (143 km), 128 naut mi (237 km), and 57 naut mi (106 km) for 24, 48 and 72 hours, respectively.

G. TROPICAL STORM IDA (08)

During the first three weeks of July, the monsoon trough extended eastward from the South China Sea to near 160°E. Areas of active convection were common during that period, with several disturbances eventually developing into significant tropical cyclones (Ida, Joe and Kim).

TD 08, the first of these disturbances which became organized, formed in the vicinity of two areas of active convection which JTWC had been tracking within the trough for several days. At 051800Z, satellite imagery indicated improved convective organization about a surface circulation near 12°N, 142°E. Aerial reconnaissance at 060145Z located a surface centre and observed maximum winds of 25 kn (13 m/sec). At 060300Z, a TCFA was issued and the initial warning followed at 060600Z, based on continued organization as indicated by satellite imagery.

Ida's track never posed a dilemma for JTWC forecasters. It initially tracked north-west before interacting with a persistent ridge whose axis was along 28°N. Maintenance of the ridge throughout Ida's lifespan was responsible for the cyclone's over-all west-northwest track and the ability of JTWC to predict landfall within 35 naut mi (65 km) of the actual point as early as 77 hours prior to the occurrence. As Ida approached the western Philippine Sea, its forward movement slowed from a maximum of 18 kn (33 km/h) to less than 10 kn (18 km/h) in the Bashi Channel. During this period, Ida reached its maximum intensity of 60 kn (31 m/sec) and lowest sea-level pressure of 980 mb. As Ida moved through the Bashi Channel, it weakened to 45 kn (23 m/sec) and then maintained this intensity until making landfall on the south-eastern coast of mainland China, just south of Shan-t'ou at 1300Z on 11 July.

A predominant feature during all but the later stages of Ida's track was a strong and persistent rain or feeder band. On 6 July, while Ida was organizing south-west of Guam, the Naval Air Station at Agana, Guam, recorded 1.15 inches (29 mm) of rain in three hours and a peak gust of 31 kn (16 m/sec) as the band passed over the island. Subsequent aircraft reconnaissance in support of the 072130Z and 090735Z position fixes noted increases in the flight level winds and temperatures while transiting this outer band. These higher flight-level temperatures and winds were an apparent response to the release of the latent heat of condensation from extensive convection within the band. The Mission Aerial Reconnaissance Weather Officer on the 090735Z fix stated, "The 700-mb centre was very weak, with no strong wind band in any quadrant close to the centre. It took us quite a while to locate a fairly broad area of light and variable winds ... The northern end of this area was open, and to the north-east we observed a broad band of surface winds peaking at 85 kn (44 m/sec) situated about 25 naut mi (46 km) out." This was not an uncommon feature from aircraft reconnaissance data on Ida. Generally these maximum winds were located in the north-east quadrant, close to the rainband. However, the 85 kn (44 m/sec) wind was considered to be a transitory feature because all other indicators showed no reason for a sudden and short-lived intensification of the cyclone.

H TYPHOON JOE (09)

Typhoon Joe, the ninth 1980 tropical cyclone in the western Pacific region, proved to be very predictable. A near-static synoptic pattern prevailed in the mid- to upper-troposphere within the subtropics throughout most of Joe's existence. As a result of this pattern, Joe followed a nearly straight track from genesis to dissipation, with few exceptions.

Joe's genesis from a tropical disturbance into a mature tropical cyclone was slow. Satellite imagery first indicated a disturbance along the equatorial trough on 14 July over the Caroline Islands. Later satellite data revealed a gradual increase of convective activity, with an apparent increase in organization. As a result of the information received from this series of satellite imagery, a TCFA was issued at 2153Z on 15 July.

The first aircraft reconnaissance of the disturbance on 16 July found a weak surface circulation which did not extend up to the 700-mb level. At that time, the minimum sea-level pressure was 1,006 mb and the disturbance was tracking north-westward at 14 kn (26 km/h). Defense Meteorological Satellite Program imagery at 0021Z on 17 July suggested that the disturbance was developing a circulation centre that extended at least to mid-tropospheric levels with strong convective activity located west of the exposed surface circulation. Weak developing tropical cyclones often have the 700-mb centre displaced from the surface circulation in the direction of strongest convective activity. As the tropical cyclone develops and intensifies, the surface circulation moves under the 700-mb centre and becomes vertically aligned.

Later satellite data did show that the surface centre had moved closer to the area of strong convection. This sequence of events prompted JTWC to issue the first

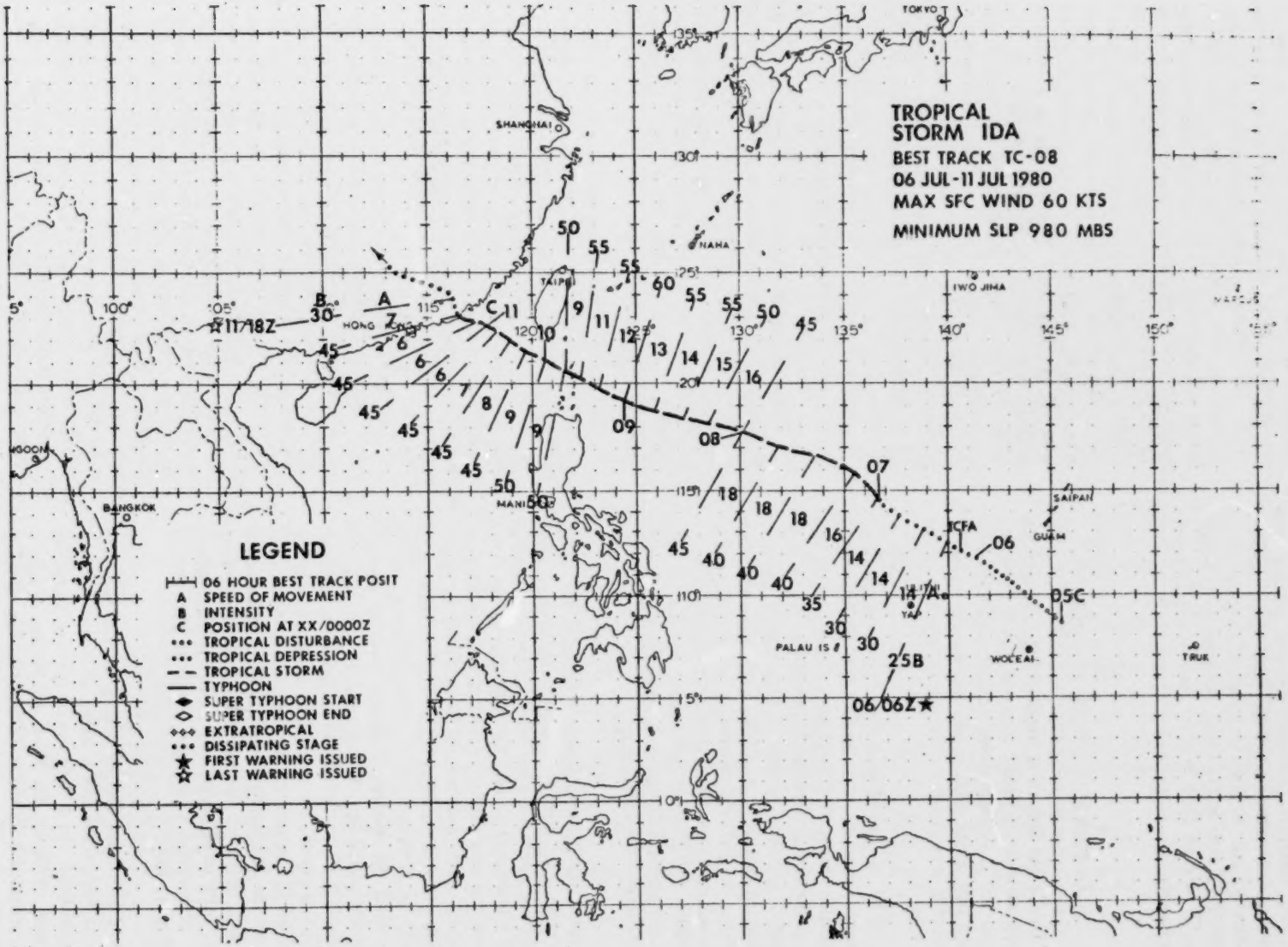

Figure 8. Tropical Storm Ida, best track

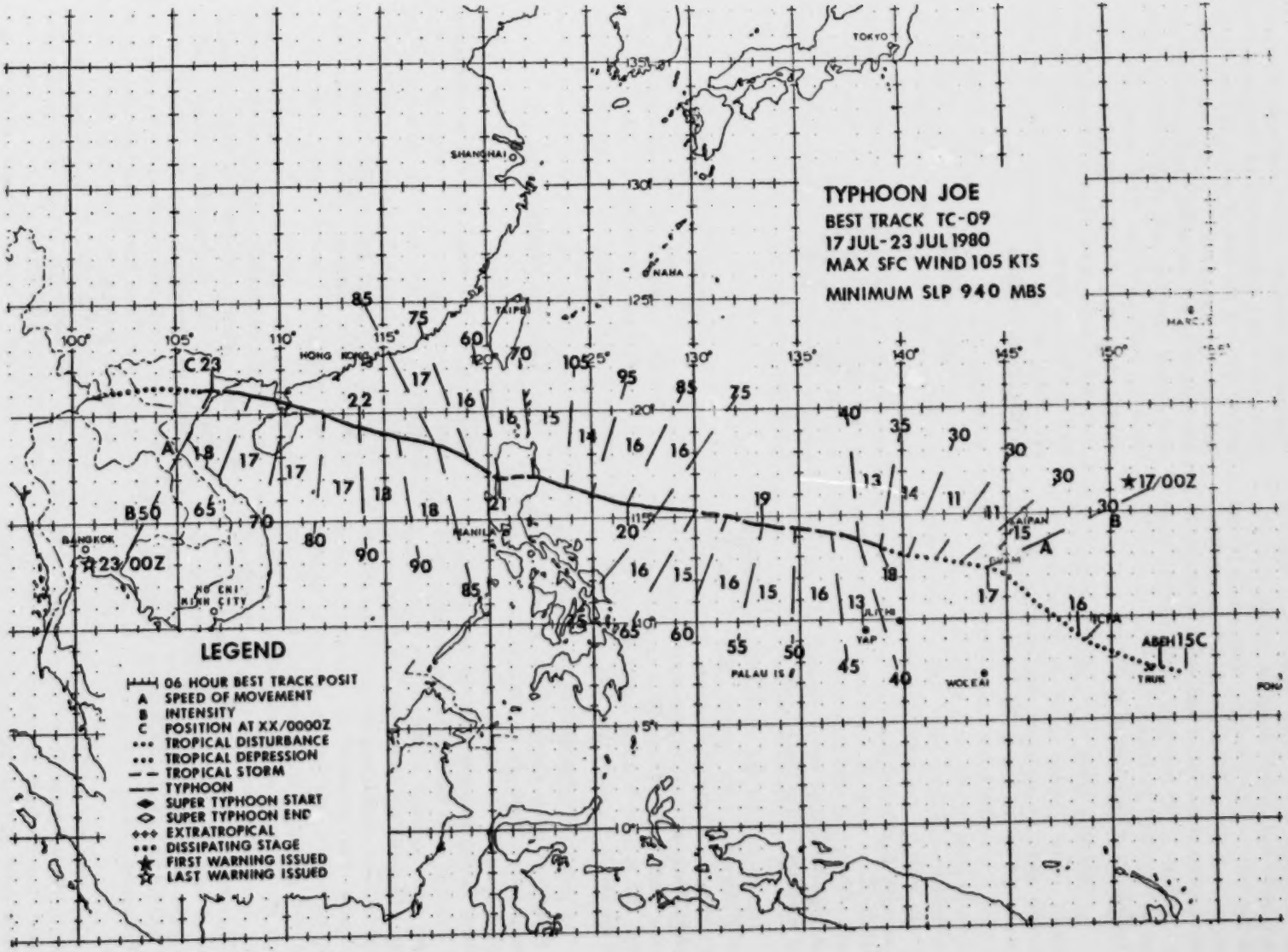

Figure 9. Typhoon Joe, best track

warning at 0000Z on 17 July for TD 09. Aircraft reconnaissance on 17 July substantiated that the disturbance had indeed developed significantly since 16 July and that the circulation centre of TD 09 had extended up to the 700-mb level, with no significant displacement of the surface and 700 mb-centre noted at that time. TD 09 developed rapidly from that point and was upgraded to Tropical Storm Joe on 18 July. Typhoon strength was attained on 19 July.

As mentioned earlier, Joe tracked along a nearly straight course through much of its existence. Its forward speed of movement was rapid and nearly constant, even while passing over Luzon. This unusually persistent track and high speed of movement was correlated with an abnormally strong mid- and upper-tropospheric subtropical ridge. The subtropical ridge at both levels deviated significantly from the climatological norm. The 200-mb anticyclone, normally located over the China mainland, extended farther east to the north of Joe's track and south of Japan. Similarly, the mid-tropospheric ridge was to the north of Joe's track and was much stronger than normal.

This pattern did not significantly change during Joe's lifetime, except briefly while it was first developing into a tropical depression. Joe's track took a slight north-westward jog in response to a short-wave trough which weakened the mid- to upper-tropospheric ridge. This short-wave trough quickly passed eastward and the ridge built back north of Joe.

Six hours prior to landfall over Luzon, Joe attained an intensity of 105 kn (54 m/sec), with a minimum sea-level pressure of 940 mb at 1200Z on 20 July. Joe weakened rapidly to tropical storm strength while crossing Luzon, but still remained very destructive. As it tracked across the mountainous terrain of Luzon, where peaks approach 10,000 ft, the track deviated slightly, becoming more westward. It took just over six hours for Joe to cross Luzon, but in that short time, the Philippines was inundated by heavy rains which produced massive flooding and resulted in extensive crop and property damage. Approximately 177,000 people were left homeless and 19 deaths were reported. Exact figures could not be compiled in time because of Typhoon Kim, which hit the Philippines within a week of Joe, compounding the destruction that the Philippines had already suffered. No significant damage was reported to United States military installations in the Philippines.

Upon entry into the South China Sea, Joe reintensified to typhoon strength. Before this time, JTWC expected Joe to track north-west onto the Asian mainland about 100 naut mi (185 km) west of Hong Kong and dissipate. The mid- and upper-tropospheric ridge, however, extended westward, causing Joe to continue on a west-northwest track toward Viet Nam. Also, from the time Joe entered the South China Sea through dissipation, it maintained a rapid speed of movement as a result of the strong ridge to the north. Typhoon Joe attained a second maximum intensity of 90 kn (46 m/sec), as determined by Dvorak analysis of satellite data. At the time of maximum intensity, the radius of winds greater than 30 kn (15 m/sec) extended 450 naut mi to the east of Joe's centre, covering most of the South China Sea north of 10°N. While transiting across the South China Sea, Joe devastated the coastal regions which paralleled its track. Much damage to crops and property occurred in southern China as a result of flooding caused by torrential rains. Joe also left many homeless and claimed more lives while tracking toward Viet Nam.

Satellite imagery showed that Joe had an eye as it made landfall near Haiphong, Viet Nam. During this period, winds were reported in excess of 70 kn (36 m/sec) by the Viet Nam News Agency. After landfall, Joe dissipated rapidly as a result of land and vertical wind shear effects. The final warning was issued by JTWC at 0000Z on 23 July, as the remnants of Joe began to dissipate over the mountains of Lao People's Democratic Republic.

I. TROPICAL DEPRESSION 10

Tropical Depression 10 reached 220 naut mi (407 km) west-northwest of Manila 13 hours prior to issuance of first warning, on 17 July 1980, 0203Z.

J. SUPER TYPHOON KIM (11)

Super Typhoon Kim, one of the most intense typhoons of the 1980 season, slammed onto the eastern coast of Luzon four days after Typhoon Joe had practically immobilized the area. Accounts of the aftermath of Typhoon Kim indicated that an estimated 15 people were killed and 167,000 residents of the Philippines were displaced. Torrential rains caused massive flooding over Luzon as far south as Manila.

Kim, the first super typhoon of the 1980 season, was first detected on satellite imagery on 19 July. The disturbance appeared as an area of enhanced convection embedded in the near-equatorial trough. Further intensification appeared likely as the tropical upper-tropospheric trough was positioned to the north-west of the convective area. Because the disturbance was in a favourable position for continued development, a TCFA was issued at 192040Z. Aircraft reconnaissance data at 200800Z indicated a well-defined closed surface circulation with wind speeds of 25 to 30 kn (12 to 15 m/sec) and a central pressure of 1,001 mb, approximately 360 naut mi (667 km) south-east of Guam. Based on these data, the first warning on TD 11 was issued at 201200Z.

TD 11 initially moved west-northwestward, passing approximately 240 naut mi (444 km) south of Guam

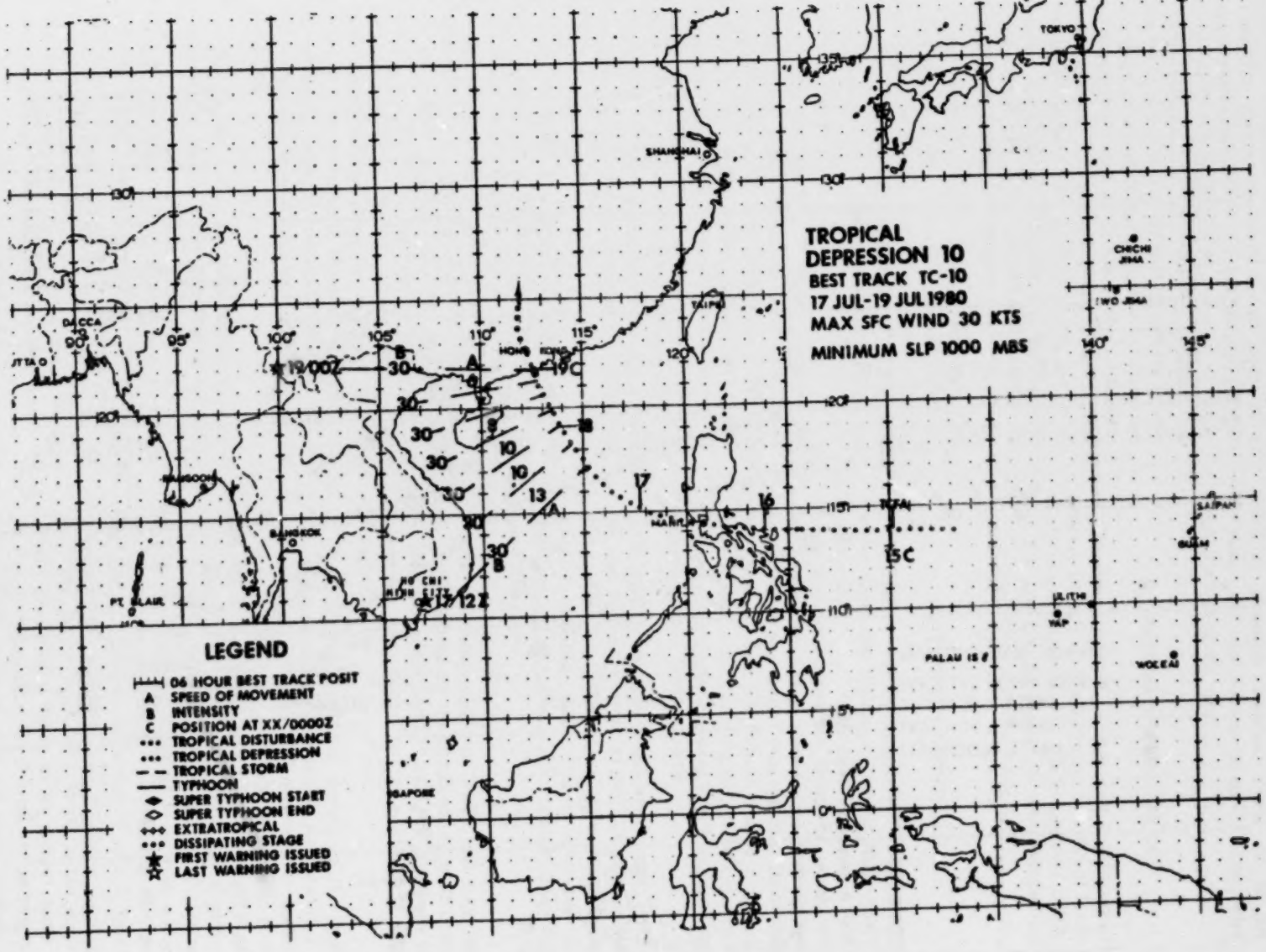

Figure 10. Tropical Depression 10, best track

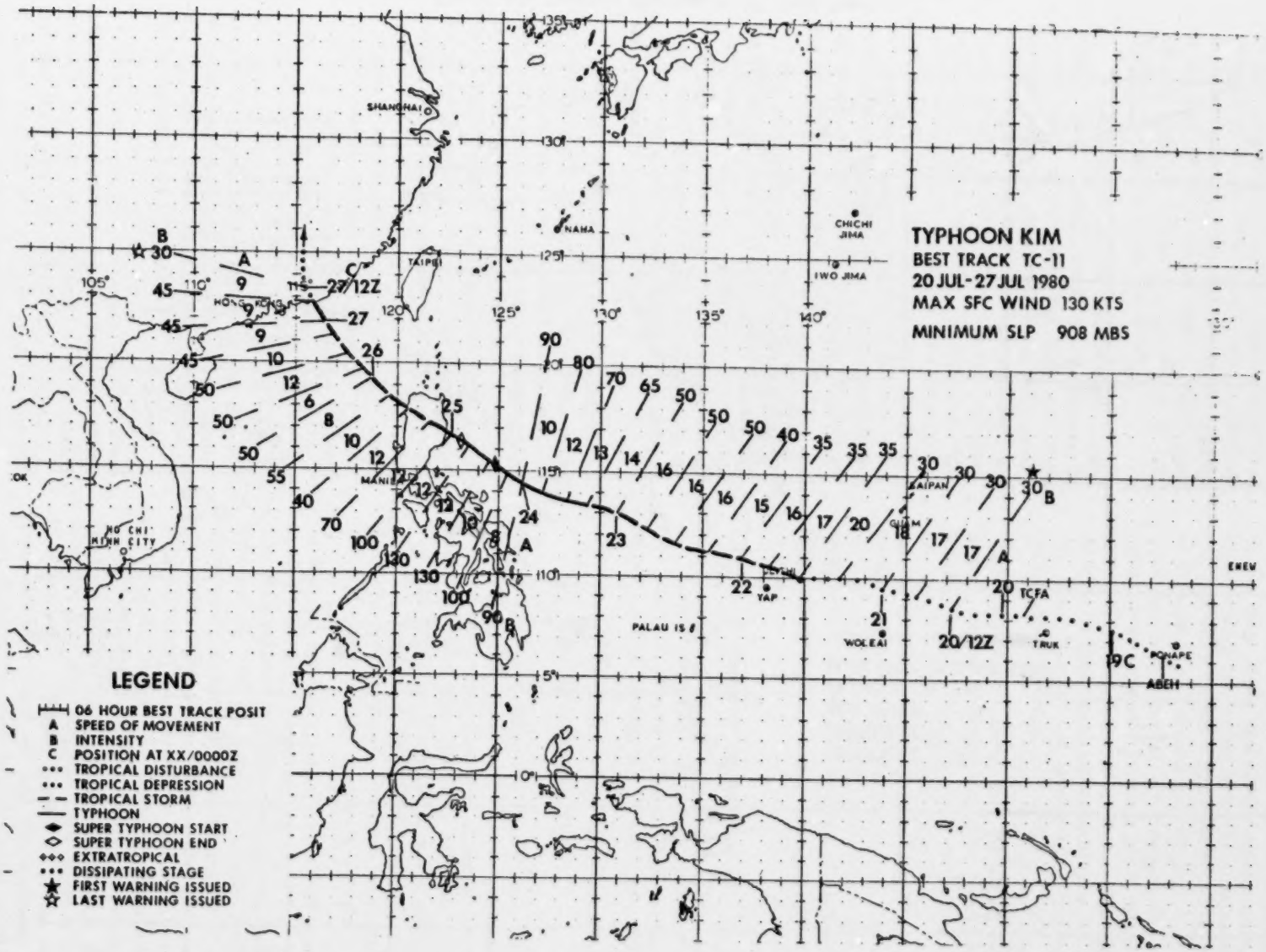

Figure 11. Typhoon Kim, best track

before heading directly towards the island of Ulithi. At 211200Z, TD 11 passed directly over Ulithi, which reported a wind maximum of 35 kn (18 m/sec). This information, plus a subsequent aircraft report of a central surface pressure of 997 mb, prompted JTWC to upgrade TD 11 to Tropical Storm Kim at 211800Z. Aircraft data at that time, however, indicated that Kim was poorly aligned in the vertical, with the 700-mb centre well to the south-east of the surface centre and the 700-mb wind flow largely disorganized. Therefore, further intensification was slow during 22 and 23 July. During this period, Kim followed a path similar to Typhoon Joe across the Philippine Sea, tracking west-northwestward along the southern periphery of the subtropical mid-tropospheric ridge.

At 230600Z, aircraft reconnaissance observed a fairly substantial drop in surface pressure to 979 mb and indications that an eyewall was partially forming. Upon receipt of the data, which signalled the beginnings of a period of more rapid intensification, Kim was upgraded to a typhoon.

During this period of falling pressures and corresponding intensification, an empirically derived forecasting aid proved very valuable to JTWC. This forecasting aid relates surface pressure and 700-mb equivalent potential temperature (θ_e) to future intensification. The hypothesis is that rapid intensification is likely to take place in a tropical cyclone within the following 12 to 36 hours after these two traces intersect. The intensification trend of Typhoon Kim verified this study.

At 241603Z, a minimum sea-level pressure of 908 mb was measured by dropsonde. This pressure was sufficiently low to qualify Kim as a super typhoon. By the next aircraft penetration, however, Kim's central pressure had risen to 918 mb. A possible reason for this rise in pressure was that Kim was now only eight hours from landfall on the coast of Luzon, and the mountainous terrain had begun to disturb Kim's low-level inflow. Shortly afterwards, at about 250000Z, Typhoon Kim moved onto the coast of Luzon with accompanying maximum sustained winds of 100 kn (52 m/sec) and reported wind gusts as high as 125 kn (64 m/sec).

The terrain further weakened Kim as it moved slowly across Luzon before emerging in the South China Sea as an ill-defined tropical storm. JTWC forecasters expected Kim to reintensify as a typhoon over the South China Sea in the same way as had Joe only several days earlier. Aircraft reconnaissance, however, continued to report that Kim lacked significant organization and that its associated convective tops were significantly lower than previously observed.

A weakness in the mid-tropospheric ridge, thought to have been induced by Typhoon Joe's passage several days earlier, allowed Kim to track more north-west towards Hong Kong. Changing little in direction or intensity as it tracked across the South China Sea, Kim finally made landfall on the coast of China 90 naut mi (167 km) north-east of Hong Kong at about 270600Z. Maximum sustained winds of 45 kn (23 m/sec) and wind gusts to 60 kn (31 m/sec) were reported as Kim moved inland.

K. TROPICAL DEPRESSION 14

Tropical Depression 14 reached 20 kn (10 m/sec) intensity just prior to landfall on the east coast of Luzon on 14 August 1980 (2317Z). TD 14 weakened rapidly over the mountains of Luzon and never reintensified over the South China Sea as was expected.

L. TYPHOON NORRIS (15)

The near equatorial trough was re-established between Guam and Ponape as Typhoon Marge moved northward toward Marcus Island on 10 August. A weak surface circulation developed along the trough axis south of Guam and slowly drifted toward the Philippines over the next two weeks. Although this disturbance never developed into a significant tropical cyclone, it played a major role in delaying the intensification of a disturbance that tracked westward from Wake Island and eventually became Typhoon Norris.

A deep tropical upper-tropospheric trough (TUTT) was first analysed on the 151200Z, 200-mb analysis over the Marshall Islands from Wake Island south-westward to Truk. Sparse surface data gave no indications of a perturbation in the low-level trade-wind flow at that time.

For the next seven days, TUTT and associated convective activity to the south-east migrated slowly westward. It was not until 211200Z that the upper-level disturbance was reflected at the surface as a weak circulation.

Convection and resultant heating of the upper troposphere increased as the disturbance approached a position north of Guam. Streamline analysis revealed the development of a sharp ridge which built north-eastward toward Marcus Island and eventually split TUTT into two cells. By 230000Z, an upper-level anticyclone had formed over the surface disturbance, and, as the disturbance continued to organize, a TCFA was issued at 230900Z. The preceding discussion illustrates the initiation of a tropical cyclone induced by upper-level divergence and enhanced convection south-east of the TUTT cell[2]. Norris tracked virtually straight west-northwestward at an average speed of 12 kn (22 km/h) from the time of first warning as a tropical depression at 240200Z until landfall on northern Taiwan, a province of the People's Republic of China, at 271600Z. This straight track was due to the strong mid-level subtropical ridge which extended

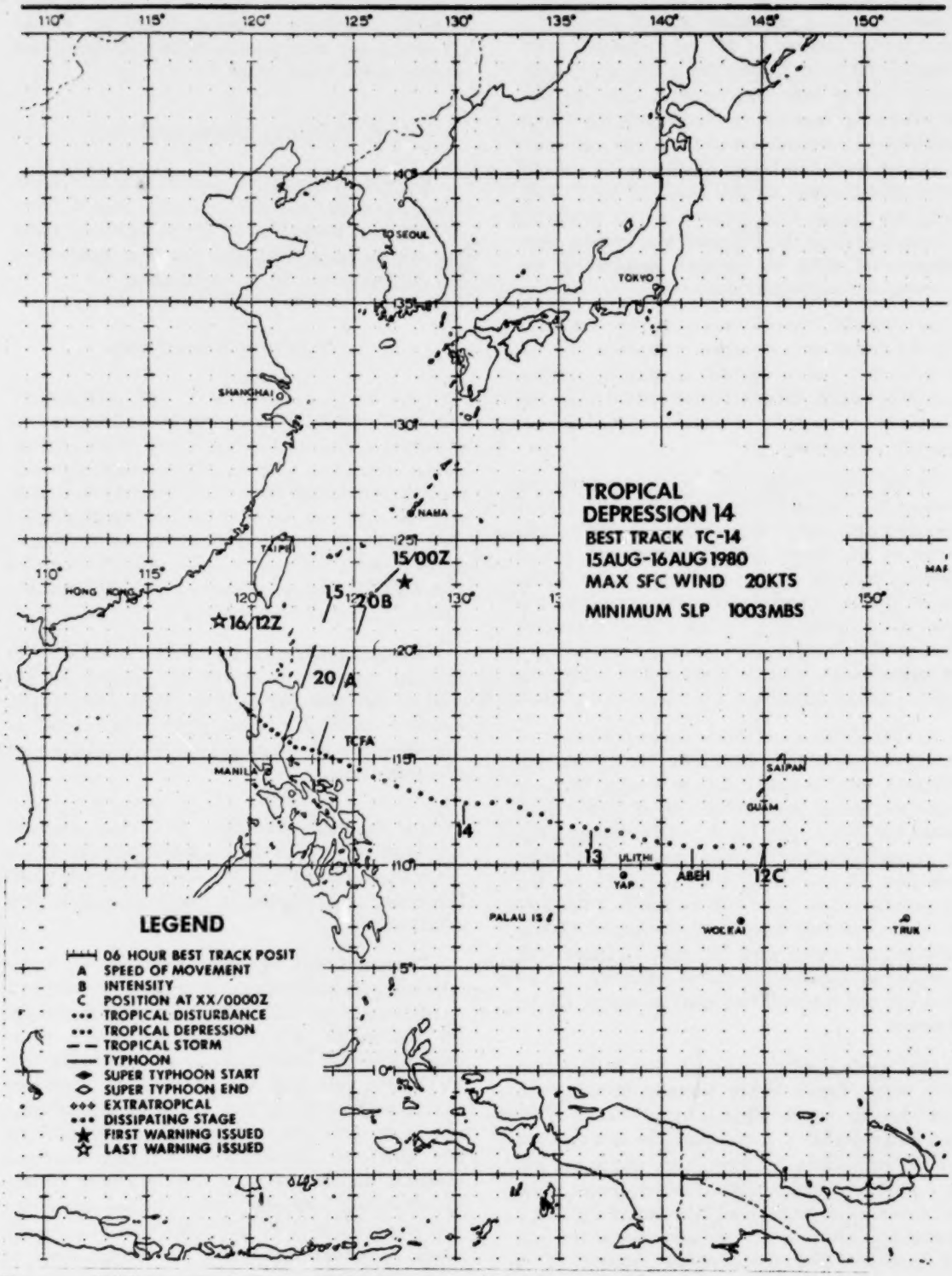

Figure 12. Tropical Depression 14, best track

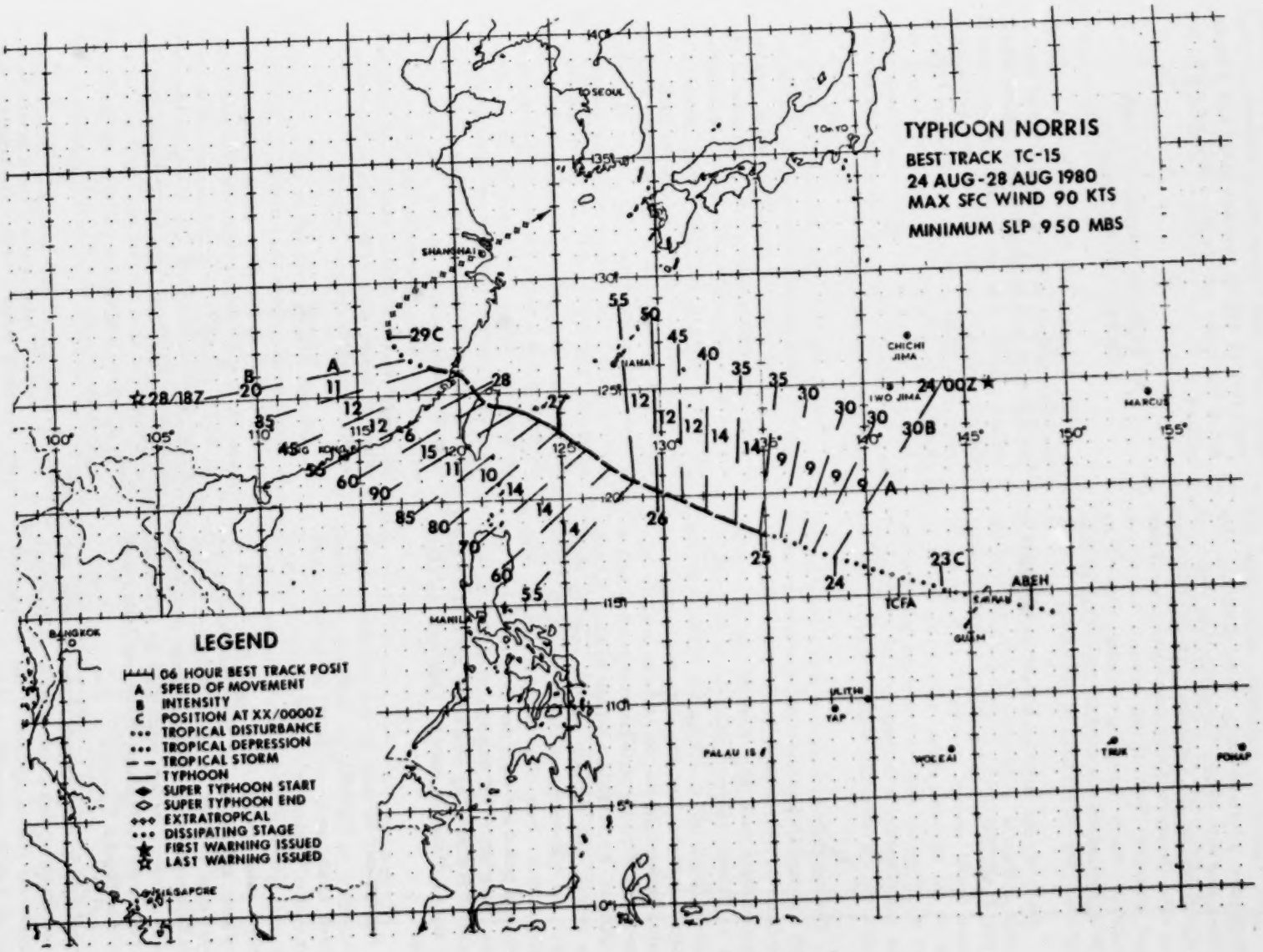

Figure 13. Typhoon Norris, best track

along 27°N from southern China eastward to the International Dateline during the latter part of August.

The circulation mentioned earlier near the Philippines prevented Norris from developing and intensifying more rapidly. The surface flow pattern was split between the two circulations until 260000Z, when the other circulation finally moved ashore over Luzon and dissipated. With all the low-level inflow now available, Norris intensified quickly from 50 kn (26 m/sec) and 985 mb at 260000Z to a peak of 90 kn (46 m/sec) and 950 mb about 36 hours later.

Norris' θ_e and minimum sea-level pressure (MSLP) curves intersected at 260000Z. On the basis of the JTWC θ_e/MSLP study (see discussion on Super Typhoon Kim), Norris' sea-level pressure was expected to fall 44 mb and maximum surface winds to increase 55 kn (28 m/sec) beyond that point. It seems very likely that this intensification would have occurred if landfall on Taiwan had not taken place within 42 hours.

The well-established mid-level ridge north of Norris, with a strong high-pressure cell located between Taiwan and Okinawa, was responsible for the climatological west-northwestward track, with Norris skirting the northern tip of Taiwan. However, with Norris 500 naut mi (926 km) south-east of Taiwan, the 260000Z, 500-mb analysis indicated that the ridge was beginning to weaken between Taiwan and Okinawa, with the high-pressure cell retreating north-eastward to a position east of Okinawa. By 261200Z, a definite break in the ridge was evident, with the high cell now over the Bonin Islands and a secondary cell located near 25°N, 112°E over southern China. The numerical forecast series during this period also supported the persistence of this break. Thus, the JTWC warnings after 260000Z were consistent in forecasting recurvature north of Taiwan and along the coast of mainland China into the Korea Strait.

Norris passed 10 naut mi (18 km) south-west of Yonagunijima at 271200Z. At that time, the island reported south-easterly winds of 80 kn (41 m/sec) and a sea-level pressure of 952.2 mb. Norris then turned to a more westward track toward northern Taiwan. Excellent radar coverage from the island stations of Ishigakijima and Miyakojima and from Hua-Lien on Taiwan permitted JTWC to follow Norris as it tracked across Taiwan and into the Formosa Strait just north of Hsin-Chu. Strongest surface winds of 39 kn (20 m/sec) with gusts to 64 kn (33 m/sec) on northern Taiwan were reported by Taipei at 271600Z.

Norris' track across Taiwan, change in speed, and observed weakening were classic examples of the effects of Taiwan on tropical cyclones[3]. The mountainous terrain of Taiwan apparently produced an induced surface low on the lee side of the mountain range, resulting in the marked increase in speed and the westward bend in Norris' track.

Landfall just south of Fu-Chou on mainland China occurred about 280900Z and, although penetrating deeper inland than forecast, Norris eventually recurved north-eastward and the remnants linked with a frontal system that moved out over the Yellow Sea and the Sea of Japan.

M. TYPHOON ORCHID (17) AND TROPICAL DEPRESSION 16

The discussion of Typhoon Orchid would be incomplete without reviewing the brief life of Tropical Depression 16. Both systems developed near the eastern extension of the monsoon trough. The dissipation of Tropical Depression 16 was followed by the subsequent development of the disturbance which became Typhoon Orchid. The influence of the monsoon trough was investigated to explain the structure of these cyclones and, ultimately, to offer an explanation for Orchid's most unusual behaviour south of Japan.

During the first few days of September, the monsoon trough was evident as far east as 160°E along 5°N. Satellite imagery on 2 September indicated increased convection near a weak circulation at the eastern end of the trough. The first of two formation alerts was issued at 021400Z. Further development was not observed on satellite imagery during the next 36 hours. A reconnaissance aircraft at 040155Z located a closed-surface circulation with 25 kn (13 m/sec) maximum winds and a minimum sea-level pressure of 1,002 mb. The first warning on TD 16 followed at 040600Z, and during the next 42 hours, JTWC tracked the depression as it moved west-northwestward. Aircraft investigations during this period showed a largely unorganized system. Unlike the investigation at 040155Z, these investigations repeatedly suggested that multiple centres existed in the area. Post-analysis indicated that some time during the 42-hour period, the surface centre associated with TD 16 weakened within the trough, while JTWC continued to follow a persistent convective centre to the west.

Although TD 16 continued to weaken, warnings were still issued because the potential for significant tropical cyclone development remained high in the region. Another disturbance eventually developed north-east of TD 16 as TD 16 weakened. Satellite imagery received at 052150Z showed that the entire area near Guam was under extensive, but apparently unorganized, convection. The final warning was issued for TD 16 when aircraft reconnaissance at 060050Z failed to locate a significant surface circulation.

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2 J.C. Sadler, "Tropical cyclone initiation by the tropical upper tropospheric trough", *NAVENVPREDRSCHFAC Technical Paper*, No. 2-76 (1976), 103 pp.

3 S. Brand, and J.W. Blelloch, "Changes in characteristics of typhoons crossing the island of Taiwan", *ENVPREDRSCHFAC Technical Paper*, No. 8-73 (1973), 21 pp.

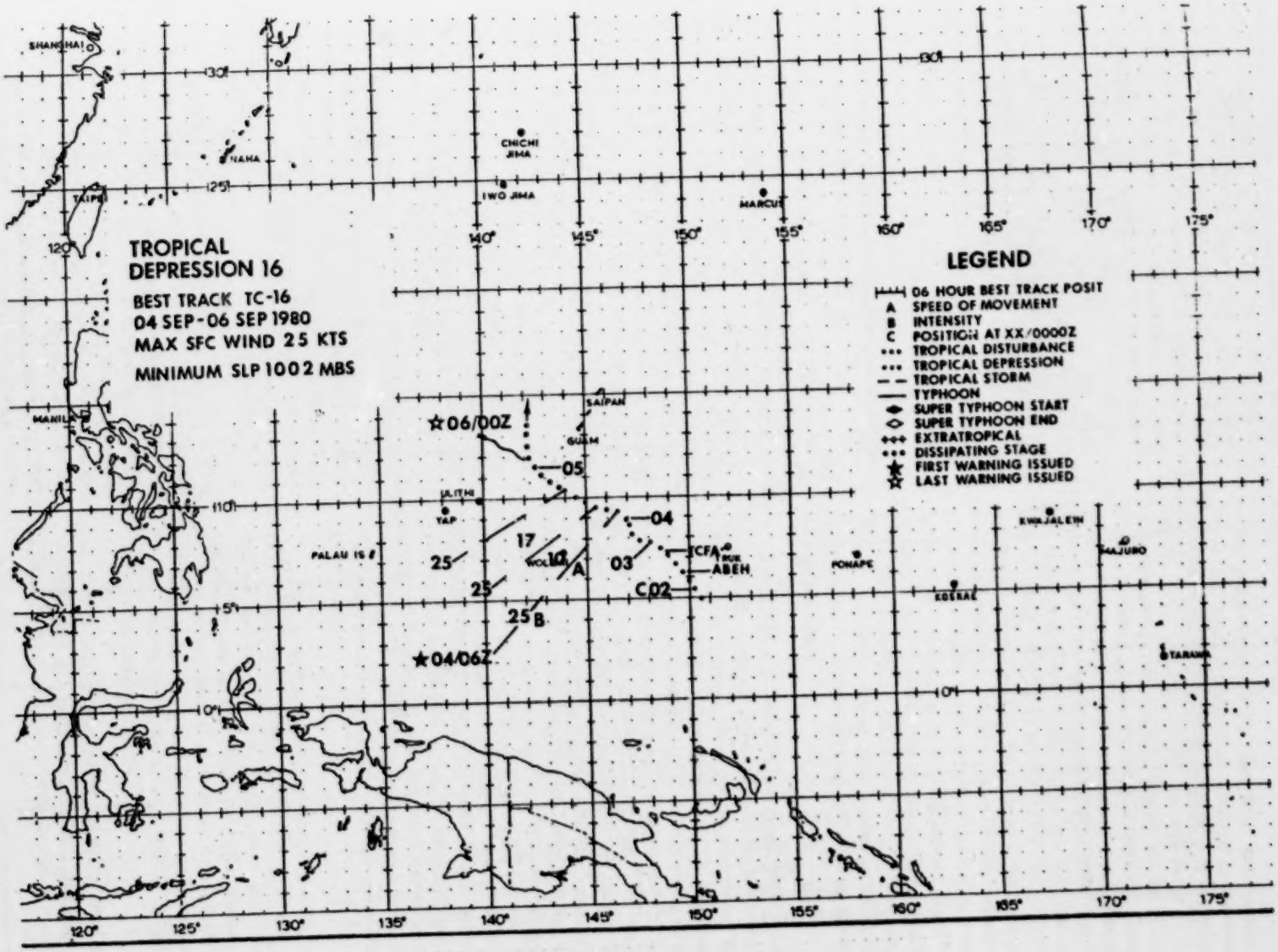


Figure 14. Tropical Depression 16, best track

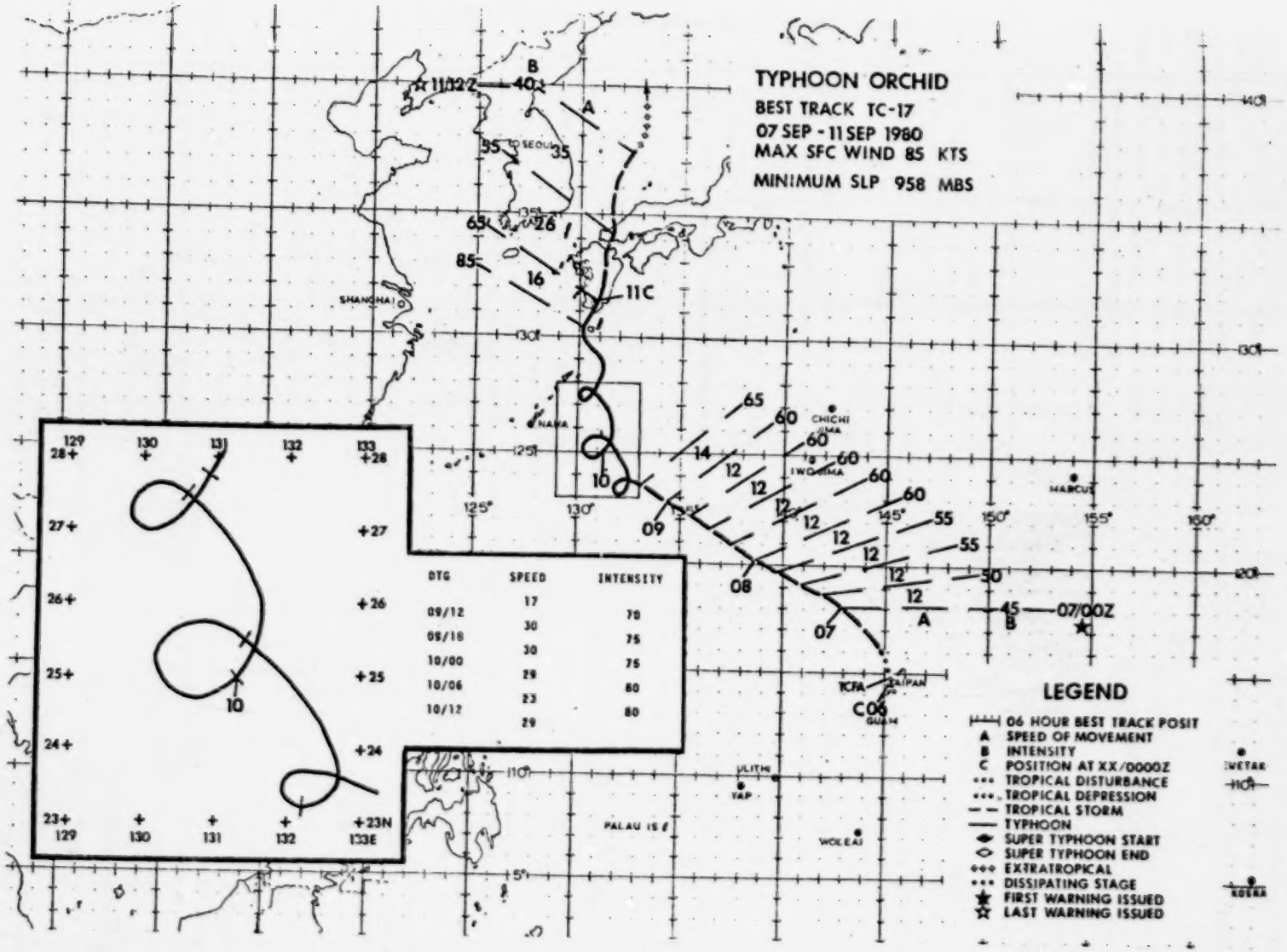


Figure 15. Typhoon Orchid, best track

By 060000Z, satellite imagery indicated that a TCFA was required for a rapidly developing disturbance just north of Guam. A reconnaissance aircraft investigated the disturbance at 060120Z but was unable to close a surface circulation. The aircraft and synoptic data showed an extensive light and variable wind area extending more than 100 naut mi (185 km) west of the disturbance. Synoptic data, nevertheless, indicated that gale-force winds (greater than 33 kn or 17 m/sec) existed in the eastern semicircle of the disturbance. After co-ordination with forecasters at the Naval Oceanography Command Center, Guam[4], a gale warning was issued for the area. The first warning for Tropical Storm Orchid was issued at 070200Z. This warning was based on aircraft reconnaissance at 070005Z, which observed 45-kn (23 m/sec) surface winds in the north-east quadrant of the storm. The same aircraft observed only 10 to 15 kn (5 to 8 m/sec) north-west winds in the western quadrant, indicating that a closed-surface circulation existed only for 6 to 12 hours before the first warning on Tropical Storm Orchid.

During the five-day period from 2 to 8 September, the axis of the monsoon trough moved from 5°N to 18°N. A near-equatorial or buffer ridge developed at low latitudes and extended from the Philippines to the east of Orchid. The pre-existing subtropical ridge north of Orchid and the presence of the near-equatorial ridge provided a broad wind band, which extended counter-clockwise from the south-southwest of Orchid to the north-west at distances as far as 800 naut mi (1,482 km) from Orchid's centre. A composite surface streamline analysis from 070000Z to 091200Z indicates that this pattern maintained itself, virtually unchanged, during a 60-hour period during which Orchid moved west-northwest at 12 kn (22 km/h). After 091200Z, the north-west wind component strengthened around Orchid as the monsoon trough began interacting with a mid-latitude trough in the eastern China Sea.

Although TD 16 and Typhoon Orchid developed in the same location with respect to the monsoon trough, it now appears that TD 16 failed to intensify because it could not sustain its own circulation pattern independently of the enhanced flow around the trough. Orchid sustained an independent circulation beginning on 7 September.

By 090000Z, Orchid had moved north into the subtropical latitudes near 23°N. The monsoon trough was showing signs of weakening, and by 091800Z, the eastern portion of the wind band collapsed into Orchid's circulation pattern. Interaction with the mid-latitude trough moving east from Asia signalled the beginning of a change in Orchid's trajectory towards recurvature. The numerical prognostic series indicated a further eastward progression of the mid-latitude trough, but the series did not reflect the presence of Orchid at the middle and upper levels of the troposphere. Initial recurvature tracks anticipated a deepening of the trough and eventual recurvature south-east of Japan. The trough stalled near 130°E, however, and the opportunity for recurvature was delayed until Orchid approached the Ryukyu Islands about 12 to 18 hours later.

In post-analysis, JTWC often finds some phenomenon that is not evident to the forecaster in real-time but which explains the motion or character of a tropical cyclone. In Orchid's case, JTWC was well aware of its circulation pattern; what was not known was the effect of this circulation pattern on Orchid's trajectory. Once formed, Orchid moved to the west-northwest at a nearly constant speed. During this portion of its track, Orchid was well-behaved and there was no known "rule of thumb" which would have provided JTWC with a prior warning of the motion that the cyclone would undergo in the 36-hour period beginning at 090600Z. Beginning at that time, Orchid executed three high-speed cyclonic loops while maintaining an over-all forward speed of 14 kn (26 km/h) toward the north. Satellite, aircraft, and radar surveillance provided dense reconnaissance coverage of Orchid during these loops. Orchid finally stabilized on its northward track just prior to landfall on Kyushu, Japan.

An analogy may provide some insight into Orchid's unexplained motion. First of all, however, some conjecture is required, based on the assumption that Orchid's circulation pattern relative to the broad-scale circulation was "conditionally" unstable; i.e., all the forces acting on Orchid were in balance only as long as it maintained a constant heading. As Orchid approached the mid-latitude trough, this balance was interrupted and the potentially unstable character of the cyclone, embedded in this particular synoptic pattern, was realized. One analogy that can be used to explain the trajectory involves a child's toy top. The top, inherently unstable because of its small base and wide body, will spin uniformly about its axis as long as it maintains equilibrium. A loss of rotational speed or a tap along the side will cause the top to stumble and the base will appear to accelerate along a predictable looping pattern until the top's stability is either restored or it comes to rest.

It is suggested here that the effect was virtually the same when Orchid began interacting with the mid-latitude trough. The best track shows that Orchid regained its equilibrium within the mid-latitude trough prior to making landfall in southern Japan. Orchid did not loop again and it returned to a slower speed of 18 kn (33 km/h) prior to accelerating during the extratropical transition period.

Orchid caused considerable damage and loss of life in Japan and the Republic of Korea. High winds and torrential rains associated with Orchid were blamed

4 JTWC functions operationally under the command of the Naval Oceanography Command Center, Guam. Destructive wind warnings for the western North Pacific are included in the services provided by the Center.

for six deaths, numerous injuries, and considerable damage to crops in southern Japan. At least three deaths were reported in the Republic of Korea as Orchid moved east into the Sea of Japan. Another 112 fishermen were reported missing in the Korea Strait following Orchid's passage.

N. TYPHOON RUTH (18)

Typhoon Ruth was the second of five typhoons which occurred in September. Unlike the other typhoons, Ruth began as a monsoon depression in the South China Sea on 11 September. For two days, the depression remained quasi-stationary, with the weak surface circulation embedded in the monsoonal trough. Synoptic data on 13 September, however, indicated that the circulation was intensifying; also, satellite imagery showed that it was forming its own outflow centre. As a result, JTWC issued a formation alert at 130047Z. Later satellite data showed that further development had occurred, which prompted the first warning to be issued on TD 18 at 130600Z.

During the early phase of development, TD 18 tracked slowly southward, steered by the near-surface wind flow. By 131800Z, TD 18 had intensified to Tropical Storm Ruth and had started to track northwestward at an accelerated forward speed of movement. For the rest of its existence, Ruth tracked along the southern periphery of the 500-mb ridge which was centred over southern mainland China. It reached its first maximum intensity of 45 kn (23 m/sec) prior to landfall over Hai-Nan Tao, but quickly weakened to minimal tropical storm strength while over the island. Ruth entered the Gulf of Tonkin on 15 September and, during its transit, rapidly intensified to typhoon strength with a maximum surface wind of 65 kn (33 m/sec) and a minimum sea-level pressure of 975 mb.

It has been repoted that vertical temperature differences between the ocean surface and the 200-ft (61 m) water depth have an important effect on the development of tropical cyclones. Approximately 90 per cent of the tropical cyclones that reached hurricane intensity in the equatorial Atlantic from 1901 to 1965 occurred where the climatological difference between the ocean surface temperature and the 200-ft (61 m) temperature was 3.9°C or less. Climatology for September shows that the Gulf of Tonkin had warm sea-surface temperatures (29°C) and a vertical temperature gradient along Ruth's track which is within the constraints reported for intensification to typhoon strength. Thus, the northern portion of the Gulf of Tonkin can serve as a sufficient heat source for tropical cyclones, such as Ruth, to intensify when conditions are favorable. This apparently is true despite the fact that the Gulf is surrounded on three sides by land.

Ruth made landfall at 160000Z south of Thanh Hou, Viet Nam. Nearly half a million people were left homeless, with 106 persons known dead or missing in Viet Nam. Ruth also caused massive crop damage and interrupted communications in the area.

After landfall, Ruth again weakened and dissipated as a significant tropical cyclone. The remnants of Ruth tracked west-southwestward for the next two days and dissipated over the Bilauk-taung Range along the border of Burma and Thailand.

O. TYPHOON PERCY (19)

The disturbance which eventually developed into the tenth typhoon of 1980 became evident on satellite imagery at 130600Z on September 1980 as a focal point of cumulus banding. This development occurred at the base of a mid-tropospheric, mid-latitude trough that extended south of Japan along 133°E. With further intensification likely, a TCFA was issued by JTWC at 132157Z. An aircraft reconnaissance investigation soon afterwards found a well-developed, closed circulation with 1,500-ft (457 m) flight-level winds of 35 kn (16 m/sec) and a minimum sea-level pressure of 992 mb. Upon receipt of these data, the first warning on Tropical Storm Percy was issued at 140600Z.

By that time, the mid-tropospheric, mid-latitude trough had moved eastward and Percy's track, in response, shifted from a northward to a more climatological west-northwestward track as the ridge extended eastward north of Percy. Percy's development was slow at this time. as scatter between satellite and aircraft fixes indicated that it was poorly aligned in the vertical. Convection on satellite imagery was displaced southwest of Percy's surface centre. The mid-tropospheric ridge that extended from eastern China along 28°N to a position north of Okinawa also restricted upper level outflow in Percy's northern semicircle. Between 15 and 17 July, however, reconnaissance aircraft consistently reported decreasing heights and increasing temperatures near the 700-mb centre.

During this time, Percy decelerated and began moving erratically. It eventually completed two tight cyclonic loops while intensifying to typhoon strength by 160000Z. Shortly afterward, at 160248Z, aircraft reconnaissance reported that the eyewall had become fully enclosed. JTWC forecast significant intensification for the next 36 hours as the θ_e forecast intensity aid (see summary for Super Typhoon Kim) indicated an approaching intersection of the 700-mb equivalent potential temperature trace and the minimum sea-level pressure trace.

During Percy's period of erratic movement, there was speculation that a Fujiwhara interaction might develop between Percy and Tropical Storm Sperry which was located 800 naut mi (1,575 km) to the east. A comparison of the post-analysis best tracks for Percy and Sperry shows that the two vortices were never

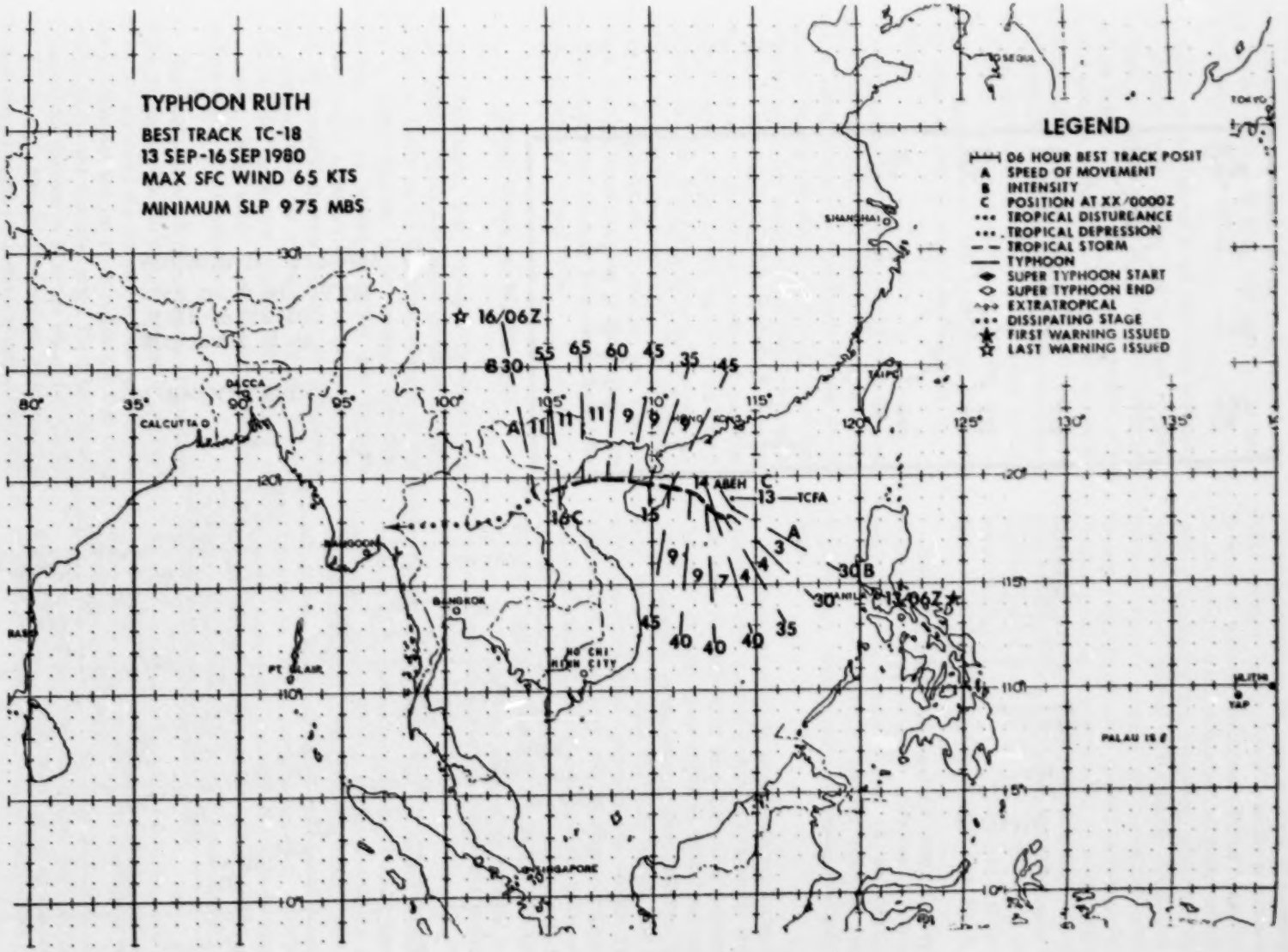
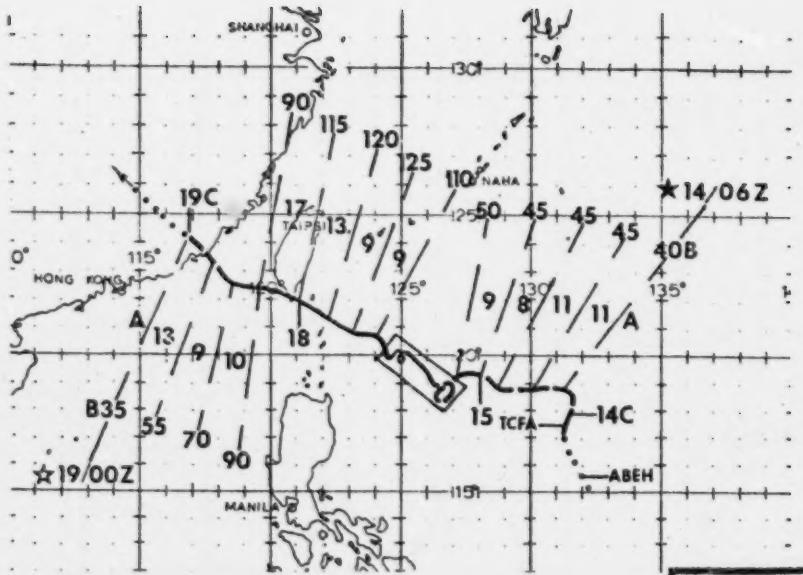


Figure 16. Typhoon Ruth, best track



LEGEND

- 06 HOUR BEST TRACK POSIT
- A SPEED OF MOVEMENT
- B INTENSITY
- C POSITION AT XX/0000Z
- TROPICAL DISTURBANCE
- TROPICAL DEPRESSION
- TROPICAL STORM
- TYPHOON
- SUPER TYPHOON START
- SUPER TYPHOON END
- EXTRATROPICAL
- DISSIPATING STAGE
- FIRST WARNING ISSUED
- LAST WARNING ISSUED

TYPHOON PERCY

BEST TRACK TC-19
14 SEP-19 SEP 1980
MAX SFC WIND 125 KTS
MINIMUM SLP 919 MBS

DTG	SPEED	INTENSITY
	06	
15/12Z		50
	07	
15/18Z		55
	10	
16/00Z		65
	04	
16/06Z		70
	04	
16/12Z		75
	09	
16/18Z		85
	11	
17/00Z		95
	10	

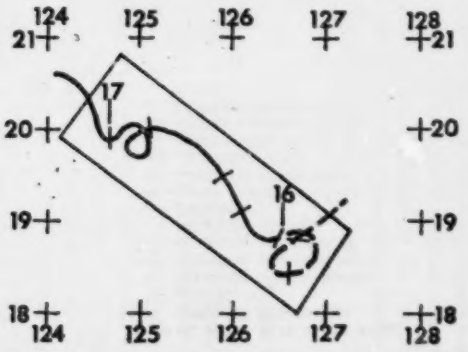


Figure 17. Typhoon Percy, best track

close enough for an interaction to occur[5]. Interestingly, Percy did dominate much of the low-level circulation pattern between the two systems. A reconnaissance aircraft mission flown between Percy and Sperry indicated that the wind shift from southerly to northerly flow did not occur until about 100 naut mi (185 km) west of Sperry's surface centre.

Significant intensification did take place as Percy's eye gradually grew tighter and sea-level pressure continued to fall. An aircraft fix at 171306Z indicated a 700-mb height of 2,387 m, which extrapolated to a sea-level pressure of 919 mb and supported maximum sustained surface winds of 125 kn (64 m/sec). Because of its proximity to Taiwan, however, Percy then began slowly to weaken. A subsequent reconnaissance aircraft at 171616Z reported a rise in the 700-mb level to 2,407 m. Approximately nine hours later, Typhoon Percy made landfall on the extreme southern tip of Taiwan.

The island of Taiwan so disrupted Percy's low-level inflow that it was never able to reintensify significantly. Despite having emerged over the Formosa Strait, Percy continued to weaken almost as quickly as it had intensified only a day earlier. By 182100Z it had made landfall on the coast of China about 240 naut mi (444 km) east of Canton, with estimated maximum sustained surface winds of 45 kn (23 m/sec). Percy continued to track inland and dissipated several hours later over the mountains of mainland China. Newspaper accounts of Typhoon Percy's landfall over southern Taiwan indicated seven dead and 16 injured. Heavy rain accompanying Percy damaged 140 homes, flooded rice fields, and destroyed banana crops.

P. SUPER TYPHOON WYNNE (23)

The disturbance that eventually developed into Super Typhoon Wynne was evident on satellite imagery as early as 1800Z on 30 September, although at that time it simply appeared to be enhanced convection embedded in the convergent inflow into Typhoon Vernon, located 1,000 naut mi (1,852 km) to the north-west. By 020000Z October, however, the disturbance had separated from the inflow into Vernon, and by 021200Z, the convective activity had increased in organization, with good curvature and upper-level outflow evident from satellite data.

The small scale of the disturbance and the tightness of the circulation that characterized Wynne during most of its life prevented the circulation from appearing on synoptic analyses and led to an underestimation of its severity during the formative stage. These facts heavily influenced the decision to delay the issuance of a TCFA for 21 hours, although post-analysis indicates that tropical storm strength was achieved as early as 030600Z. Because of its proximity to Guam, numerous aircraft reconnaissance missions were flown into the developing tropical cyclone. This extensive coverage confirmed Wynne's small circulation and permitted JTWC to monitor its development very closely.

Although Typhoon Lex may have been the most interesting cyclone of the year in terms of movement, Super Typhoon Wynne proved to be the most unusual in terms of intensity oscillations. Wynne's early stage of development was characterized by short periods of rapid intensification and weakening, rather than by a typical smooth, gradual intensification. From 3 to 7 October, Wynne's intensity and convective activity fluctuated significantly as it attained typhoon or near-typhoon strength, only to weaken to nearly tropical-depression intensity three times following a diurnal cycle. Although not as marked as the oscillations in the observed maximum winds, the minimum sea-level pressure also exhibited a cyclical oscillation that closely approximated the periodicity of the maximum winds.

There have been documented cases of tropical cyclones exhibiting intensity variations[6]. However, these occurrences were limited to well-developed typhoons with minimum sea-level pressures below 970 mb and with a single weakening-reintensifying cycle.

An examination of the satellite imagery during this period of large short-term changes in intensity reveals that maximum activity in deep convection occurred in the early morning hours (0700 to 0800 local time), with a minimum in the evening hours (1900 to 2000 local time). An increase in cirrus toward the late afternoon (1600 local time) was also evident. These observations agree with the findings of Arnold[7]. Although Arnold found no evidence of changes in intensity accompanying the alteration in cirrus or deep convection, a significant intensity change was observed in the case of Wynne, with a lag of six to eight hours between maximum convective activity and maximum observed winds.

Wynne's third and final period of weakening occurred as it tracked 45 naut mi (83 km) north-east of Guam. This weakening, combined with its small circulation, resulted in Wynne having virtually no effect on Guam. Wynne continued to intensify rapidly following its third reintensification cycle at 071800Z, attaining super-typhoon strength just 30 hours later and a peak intensity of 150 kn (77 m/sec) in another six hours. MSLP during this 35-hour period dropped from 982 mb to 890 mb (a 31 mb/12 h fall).

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5 S. Brand, "Interaction of binary tropical cyclones of the western North Pacific Ocean", *NAVWEARSCHFAC TECH REPORT*, No. 26-68 (1968).

6 C.R. Holliday, "Double intensification of Typhoon Gloria, 1974 and a brief review of similar occurrences", *FLEWEACHEN TECH NOTE*, No. 76-1 (JTWC, 1976), 16 pp.

7 C.P. Arnold, "Tropical cyclone cloud and intensity relationships", *Dept. of Atmos. Sci. Paper*, No. 277 (Colorado State University, Ft. Collins, Colorado, 1977), 155 pp.

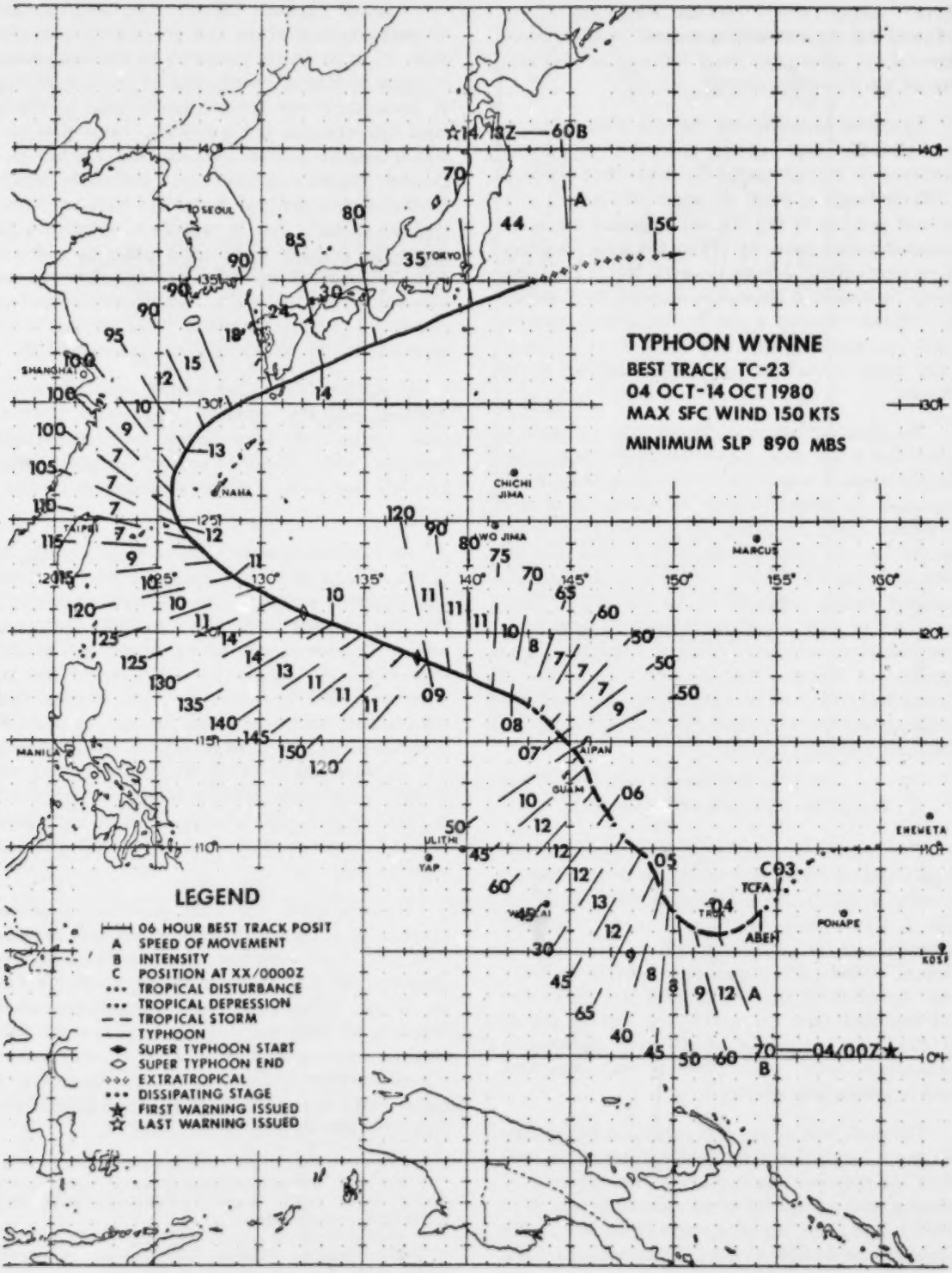


Figure 18. Typhoon Wynne, best track

The JTWC θ_e/MSLP study once again accurately predicted this explosive deepening as the θ_e and MSLP trace intersected at 081400Z. Wynne's intensity peaked 16 hours after the time of intersection, with the surface winds increasing by 85 kn (44 m/sec) and the MSLP falling another 62 mb.

As Wynne tracked north-northwestward past Guam, it was expected to move through an apparent weakness in the subtropical ridge north of Guam. However, the weakness between 25°N and 30°N was evidently too far north to permit it to break through the ridge, and it eventually came under the influence of the strong anticyclone located between Okinawa and the Bonin Islands. Post-analysis of available 500-mb data indicates that a change to a more westward forecast track around the southern periphery of the anticyclone could have been made 24 hours earlier. Once the forecast track was changed to reflect the shift in the synoptic flow pattern to a more definitive easterly steering current, JTWC was consistent in accurately predicting a recurvature just west of Okinawa. Wynne actually recurved 100 naut mi (185 km) west of Okinawa, and its slow, 7-kn (4 m/sec) bend around the island brought over two days of torrential rain and winds gusting at more than 65 kn (33 m/sec). Very few injuries were reported, with farm crops receiving the major wind damage. A small island 30 naut mi (56 km) north-west of Okinawa and closer to Wynne's path, however, reported winds of 100 kn (51 m/sec) and severe damage.

Once north of the ridge axis, Wynne tracked virtually straight east-northeastward on a heading of 70 degrees. This course kept it approximately 80 naut mi (148 km) from the coast of Japan. Winds of 30 to 45 kn (15 to 23 m/sec) were reported by Japanese coastal stations as Wynne accelerated north-eastward. Heavy rains claimed several lives and flooded over 1,000 homes.

As Wynne accelerated past Japan at speeds exceeding 40 kn (74 km/h), the vertical wind shear and the influx of cooler, drier air resulted in rapid extratropical transition. A reconnaissance aircraft at 141500Z was unable to find a circulation at 700 mb and satellite imagery at 141800Z revealed no active convection. The remnants of Wynne eventually were absorbed by a developing low-pressure system east of Japan.

Q. TYPHOON BETTY (25)

Betty, the twenty-fifth significant tropical cyclone of 1980, developed east of Truk Atoll from a weak disturbance which had been monitored for almost a week in the eastern Caroline Islands. Just prior to passing south of Guam, Betty attained typhoon strength and then continued to intensify as it tracked into the Philippine Sea. About 12 hours prior to landfall on Luzon, Betty reached its peak intensity of 125 kn (64 m/sec). During the 18 hours that Betty tracked over north-central Luzon it weakened considerably, but in the process caused extensive damage and loss of life. Downgraded to tropical storm strength, Betty moved north-eastward through the Bashi Channel and eventually dissipated as a weak, extratropical low south-east of Japan.

Betty had its origin in a weak disturbance south of Truk which showed increased potential for development on 27 and 28 October. The 280000Z gradient level winds from Truk and Ponape, as well as low-level winds from a weather reconnaissance flight west of the disturbance, indicated a closed circulation with 20 to 25 kn (10 to 13 m/sec) winds. At 280800Z a TCFA was issued and during the alert period the disturbance veered sharply to the east as it approached Truk on an erratic course from the south. After veering, hourly reports from Truk and satellite imagery indicated increased organization, and the first warning for TD 25 was issued at 290000Z, with maximum surface winds at 30 kn (15 m/sec).

Despite the erratic movement shown during its formative stages and the apparent north-eastward trajectory which TD 25 had assumed by the first warning, the initial and subsequent warnings correctly identified a west-northwest track which indicated its passage just south of Guam. However, because of limited mid-level (700-mb or 500-mb) steering data north of Betty, the first six warnings failed to forecast its acceleration adequately, which resulted in a speed of movement of 21 kn (39 km/h) as it passed Guam. Consequently, although the 72-hour forecast position of the second warning predicted Betty's exact position as it passed south of Guam, the average vector error during this period was very high. The 72-hour forecast position mentioned above had a total error of 585 naut mi (1,083 km) produced by the acceleration, which caused Betty to reach the 72-hour point in just 34 hours! Such errors, resulting from under-forecasting the speed of movement, highlight the importance of adequate mid-level data in the steering current. When available, especially when obtained by reconnaissance aircraft, such data usually increase the ability of forecasters to evaluate both the potential for changes in the short-term and the long-term motion of tropical cyclones.

After passing south of Guam, Typhoon Betty turned west and continued to intensify, reaching 100 kn (61 m/sec) 48 hours later. During this period, the 500-mb analyses began to show a short-wave trough moving east through mainland China. JTWC forecasts keyed on this feature and, on the basis of computer-derived prognostic charts, recurvature was expected to begin near 125°E by 030000Z. The probability that this forecast was correct increased when, at 020000Z, the short-wave trough deepened as it moved off Asia. However, by 021200Z, Betty unexpectedly turned

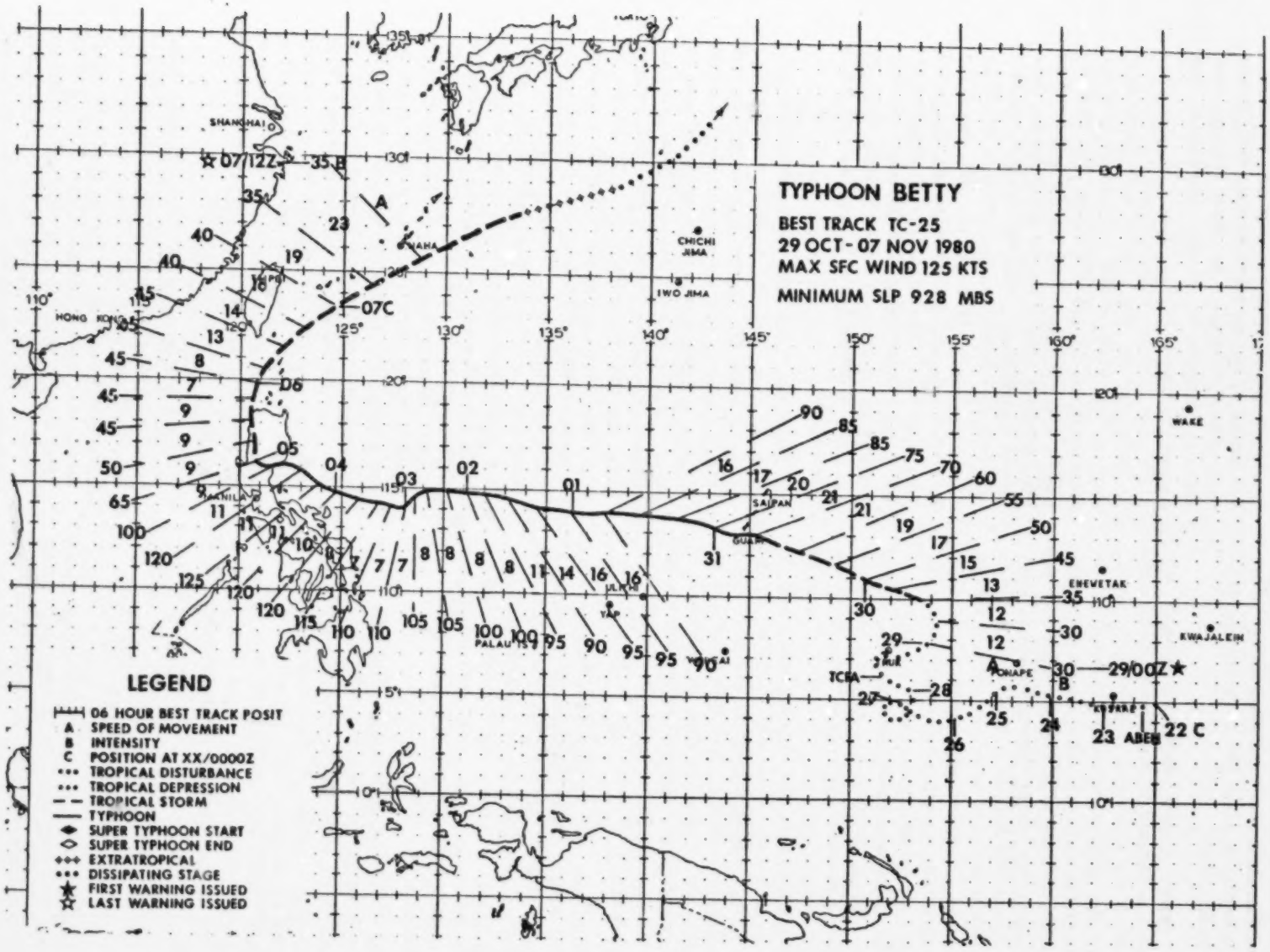


Figure 19. Typhoon Betty, best track

south-westward. By 030000Z, the trough had moved quickly eastward north of Betty and the opportunity for recurvature had passed. Shortly afterwards, attention focused on another short wave moving through China and recurvature was again forecast, this time just east of Luzon. by 040000Z, however, available 500-mb data did not show any significant amplitude to this trough and the recurvature track was abandoned in favour of a north-westward track over Luzon into southern China.

Although Betty continued to intensify after passing Guam, the data normally used to evaluate the intensity of a tropical cyclone showed considerable scatter. In searching for an explanation of the scatter, the comments from Mission Aerial Reconnaissance Weather Officers on 1 November and 4 November may offer some insight concerning the character of Betty during this period. On the 011594Z mission, it was observed that "Although this storm [Betty] was strong, it had no eyewall. The most fascinating feature was the rotating feeder band of convection that was spiralling inward at an enormous rate." On this single-fix mission, a maximum 700-mb flight level wind of 95 kn (49 m/sec) was observed. However, daylight missions before and after this mission estimated surface winds in excess of 100 kn (51 m/sec). On the 032200Z, 040150Z and 040340Z fix missions, it was observed that "Typhoon Betty ... was a textbook typhoon. Everything was aligned perfectly." At 040600Z, Betty reached its peak intensity of 125 kn (64 m/sec). The development of a textbook typhoon correlated closely with the reduction in scatter between maximum surface wind estimates.

The decision to abandon a forecast recurve track east of Luzon put the central and northern provinces of Luzon on alert. At 041600Z, Typhoon Betty, packing 120-kn (62 m/sec) winds, slammed into central Luzon south of Cape San Ildefonso. Most weather-observing stations stopped reporting prior to Betty's approach, so its actual intensity as it crossed Luzon can only be inferred from a JTWC study of prior tropical cyclones crossing the Philippines, by Sikora[8], satellite imagery (Dvorak intensity estimates) and aircraft reconnaissance reports just before and after Betty crossed Luzon. However intense Betty may have been, there is little doubt that it was one of the most destructive typhoons in recent history. Initial reports received several days after Betty crossed Luzon indicated at least 81 people dead, thousands homeless, and extensive crop damage from flooding and mudslides. The Cagayan Valley in northern Luzon, hard hit by Betty, lost most of its rice crop from flood waters which rose to roof-top levels in some areas. Philippine Defense Minister, Juan Ponce Enrile, describing the Cagayan Valley during a helicopter survey, stated, "It looks like a sea from the air."

As Betty weakened over Luzon, the ridge that had influenced its track into the Philippines broke down, thus allowing it to drift northward along the Cordillera Central Mountains and eventually to be drawn into the weak, short-wave trough which had stalled off the coast of Taiwan. Emerging from Luzon as a 45-kn (23 m/sec) tropical storm, Betty never regained its earlier fury as it moved east of Taiwan and the Ryukyu Islands before undergoing an extratropical transition just prior to 080000Z. As an extratropical system, the remnants of Betty did not persist long. This once-powerful typhoon was last observed 12 hours later dissipating south-east of Honshu, near 32°N, 143°E.

R. TROPICAL STORM CARY (26)

Tropical Storm Cary was first observed as a area of increased convective activity east of the Palau Islands on 25 October. A TCFA was issued a day later, when the disturbance had moved to a position about halfway between Yap and the Palau Islands.

All convection associated with this circulation dissipated shortly afterward, however, leaving only an exposed, low-level circulation centre. Over the next 24 hours the system moved west-northwestward toward the Philippines. Just east of the Philippines, the convection again developed and 30 kn (15 m/sec) winds were reported from coastal stations. On the basis of this information, a second TCFA was issued at 282200Z.

The circulation maintained its identity as it passed over the Philippines just south of Clark Air Base and Subic Bay Naval Station. The first warning on TD 26 was issued at 291200Z, as the disturbance was moving into the South China Sea. Tropical storm strength was reached six hours later.

Tropical Storm Cary moved west-northwestward and then west-southwestward in response to a low-level north-east monsoonal surge and eventually dissipated over Viet Nam on 2 November.

S. TYPHOON DINAH (27)

Dinah, the final Pacific typhoon of the 1980 season and the third tropical cyclone this season to threaten Guam, began to develop in mid-November as a focal point of cumulus banding embedded in the monsoon trough oriented east-west near Kwajalein. Initial development of this system was slow and erratic; four successive TCFAs were issued for this area between 18 and 20 November. On 21 November, however, this system finally established a well-developed outflow pattern, and its heaviest associated convection, which was initially more evident along the periphery of the circulation, began to consolidate about the centre of the system. The first warning on Tropical Storm Dinah was issued at 210600Z. At that time, having established

8 C.R. Sikora, "A re-evaluation of the changes in speed and intensity of tropical cyclones crossing the Philippines", *FLEWEACEN TECH NOTE*, No. 76-2 (JTWC, 1976), 11pp.

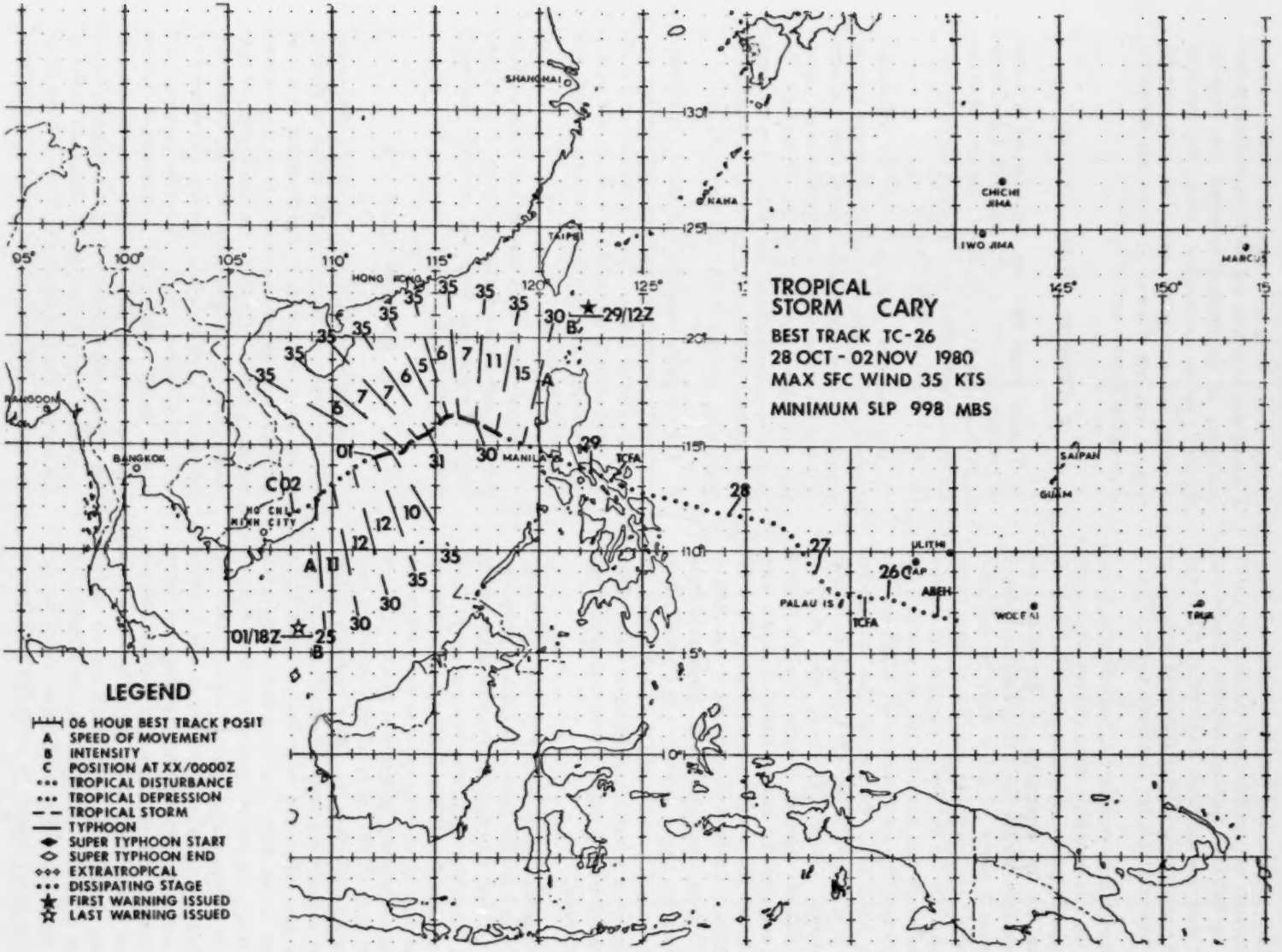


Figure 20. Tropical Storm Cary, best track

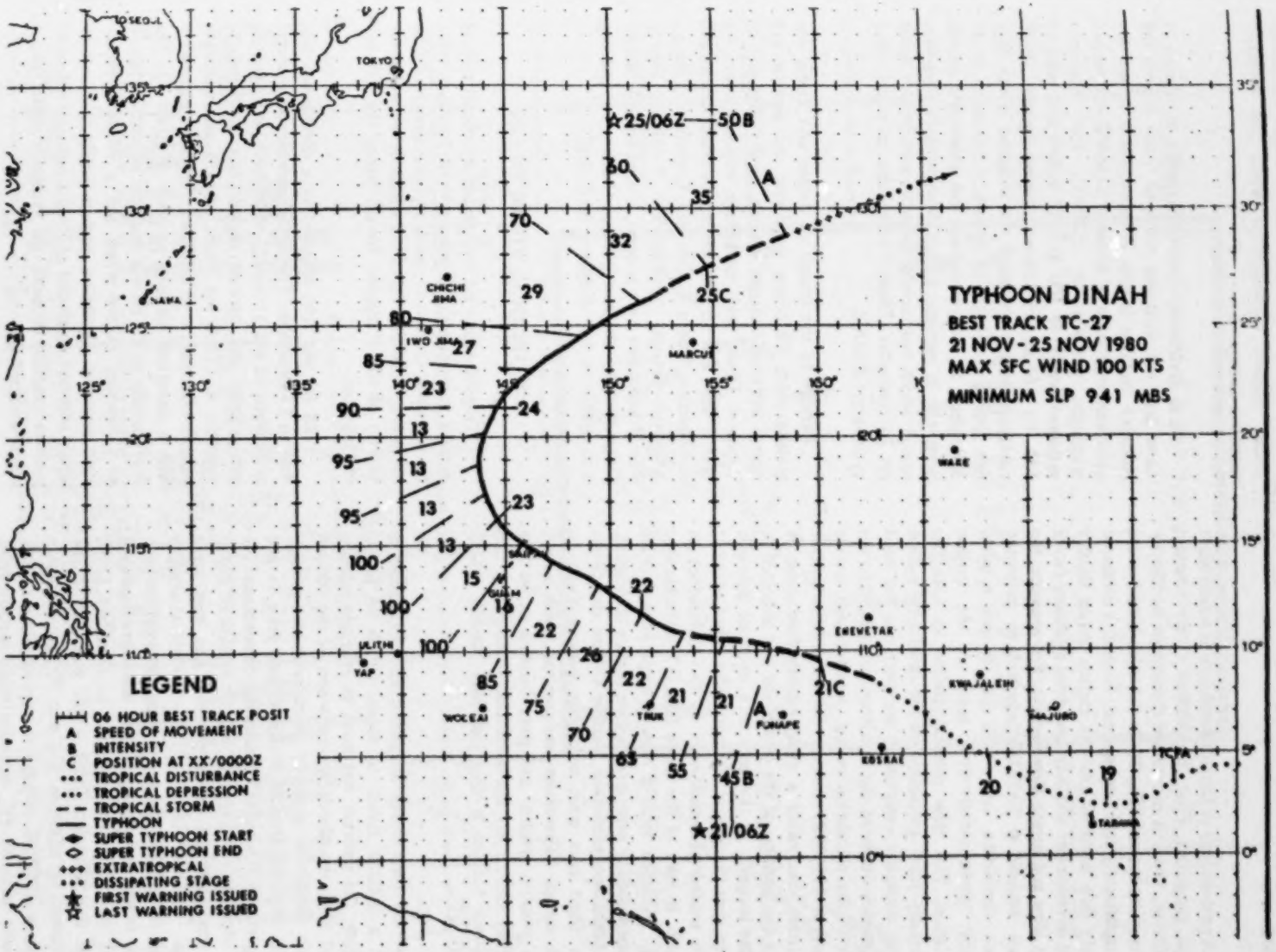


Figure 21. Typhoon Dinah, best track

a well-developed outflow to all quadrants, Dinah intensified rapidly and subsequently reached typhoon strength at 211800Z, just 12 hours after the initial warning.

A post-analysis of Dinah's development reveals some unique properties. First, it exhibited a very compact circulation, which it maintained throughout its lifespan as a tropical cyclone. The 30-kn (15 m/sec) wind radius was significantly less than normal. Second, a persistent easterly flow occurred near the surface during Dinah's initial development and may have been a primary factor in its slow and erratic development. For example, the surface analysis at 200000Z indicated an associated surface circulation near 4°N, 168°E and a brisk, easterly, gradient-level flow north of the surface circulation. This flow pattern resulted in both the abnormally rapid movement of the developing system and an unusually pronounced asymmetry in her wind field, which displaced the maximum wind band to the north of the circulation centre. A subsequent surface analysis at 211200Z, however, did not indicate surface circulation, but rather a weak, easterly flow south of where the position of the circulation was indicated in satellite imagery. At the same time, cyclonic flow was present over the area at 500 mb, and a closed cyclonic centre existed just north-west of the disturbance at 200 mb. In view of the above data, it is probable that Dinah developed from a mid- or upper-level cyclone that subsequently generated its own surface circulation. The Aerial Reconnaissance Weather Officer aboard the initial flight into what ultimately became Typhoon Dinah stated, "The storm was compact, with a very sharp pressure gradient and good banding ... We had difficulty closing off the circulation to the north and north-west because it may just have actually closed [itself] off".

By the time Dinah intensified into a typhoon, it posed a definite threat to Guam within 48 hours; therefore, the decision was made to evacuate military aircraft from the island. A comparison of the 500-mb analysis (which is generally considered the primary steering level for tropical cyclones) just prior to and subsequent to the aircraft evacuation demonstrates the great importance of enroute aircraft reports of flight-level winds and the significance they can have for a tropical cyclone forecast. The 500-mb streamline analysis at 211200Z showed a strong anticyclone near Marcus Island and strong ridging west-southwestward toward the Philippine Islands. In response, JTWC forecast that Typhoon Dinah would pass just off the north-eastern tip of Guam. The next 500-mb streamline analysis, at 220000Z, which was augmented by a series of reports taken by an evacuation flight enroute from Guam to Okinawa, enabled JTWC to analyse a weakness in the ridge just north of Guam. In view of this new information, JTWC amended Dinah's forecast track to predict that Dinah would track near Saipan *vice* Guam. Because Dinah was so compact, this small change in track was enough for Guam to receive very little wind as Dinah passed to the north-east, but Saipan and nearby Tinian received typhoon-force winds and sustained extensive damage.

Dinah continued to intensify rapidly as it began to move into the weakness north of Guam toward the Northern Marianas Islands. It subsequently crossed the north-eastern portion of Saipan at 221845Z and reached maximum intensity at 222100Z, with maximum sustained winds of 100 kn (52 m/sec) and gusts to 130 kn (67 m/sec). After crossing Saipan, Dinah continued to move through the weakness in the ridge near 140°E and began to recurve to the north on 23 November. It then weakened and accelerated to the north-east in response to a mid-tropospheric long-wave trough which was moving eastward past Marcus Island on 24 November. Dinah had become an extratropical cyclone by 251200Z.

Damage to the islands of Saipan and Tinian was massive, with 60 homes destroyed and another 214 homes suffering damages. Saipan, in the aftermath of Typhoon Dinah, was completely without power for several days and 85 per cent of the water system did not function. Carlos S. Camacho, Governor of Saipan, estimated damages totalling $US 7 million. Shortly after the damages were assessed, United States President Carter declared the area a major disaster area, enabling it to qualify for federal disaster fund relief.

T. TROPICAL STORM ED (28)

Tropical Storm Ed was the last significant tropical cyclone to develop in the western North Pacific in 1980. Ed was never forecast to reach typhoon strength due to the strong vertical wind shear which developed in the vicinity of the Philippine Islands during the last half of December.

TS Ed was first observed as a disturbance near Yap on 14 December. The disturbance moved westward at between 12 and 15 kn (22 to 28 km/h) as its convective activity and over-all organization continued to improve. A TCFA was issued when a reconnaissance aircraft observed a well-defined, low-level circulation with a minimum sea-level pressure of 1,004 mb. The first warning on TS Ed was issued at 160000Z when 50 kn (25-m/sec) surface winds and a 991-mb pressure were reported. Maximum surface winds were consistently observed north-east of Ed in a region of enhanced pressure gradient between the cyclone's centre and a strong surface ridge.

It became evident from synoptic analyses that TS Ed was moving into an area which was unfavourable for continued development. The strong surface ridge extended from the Asian mainland into the Pacific

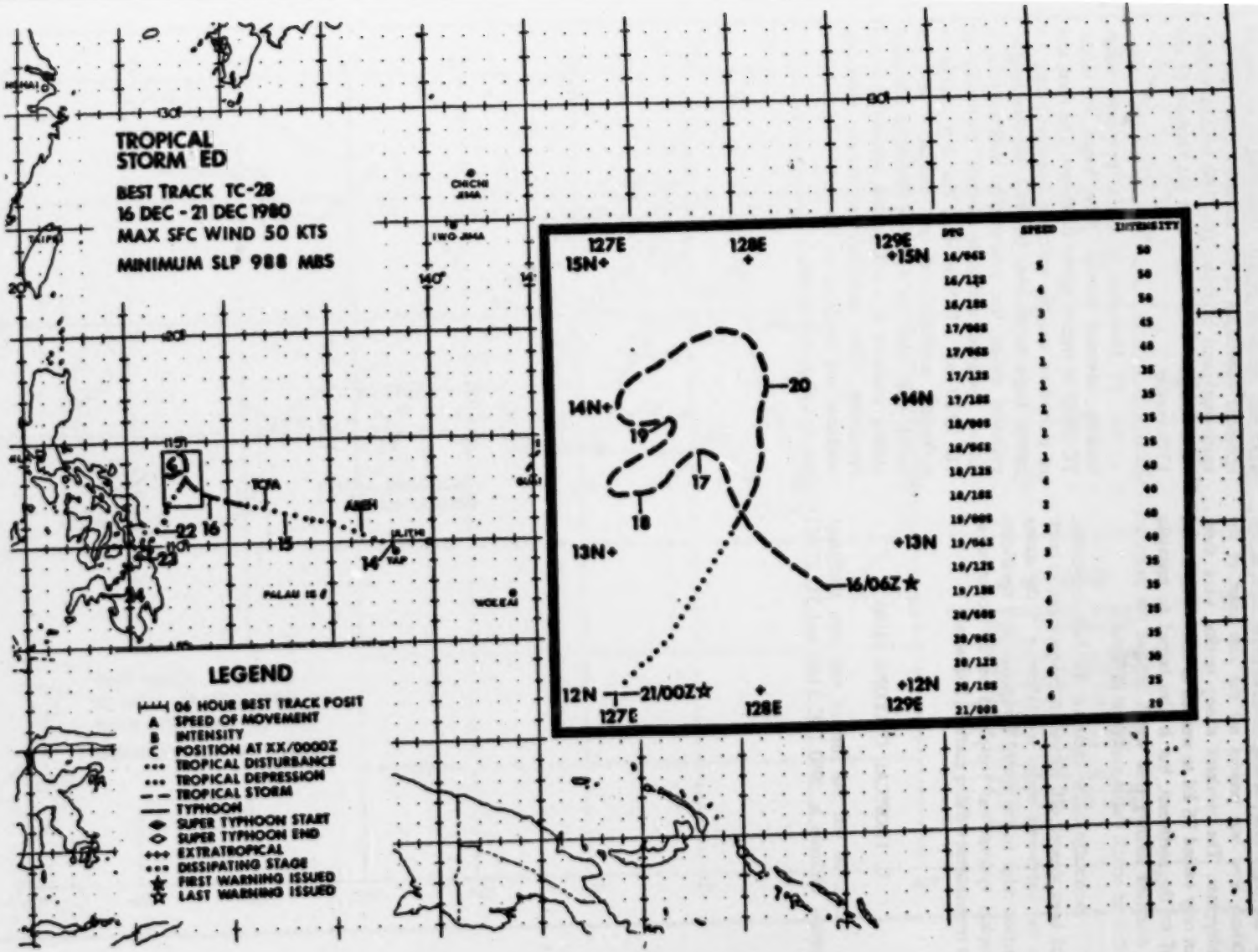


Figure 22. Tropical Storm Ed, best track

Ocean north of Ed and maintained a strong, north-easterly, low-level flow in the vicinity of the Philippines. At the same time, strong south-westerly flow at the 200-mb level was present off the east coast of the Philippines. The resultant strong vertical wind shear not only caused TS Ed to weaken as convection moved off to the north-east, but it also helped to maintain a confused steering flow which induced the storm to follow an erratic course north-east of Simar.

Eventually, after most of TS Ed's convection had been sheared off, its surface centre began to track to the south-west under the influence of the strong surface ridge to the north. Dissipation as a significant tropical cyclone was completed on 24 December as its remnants moved into northern Mindanao.

U. TROPICAL CYCLONE 23-80

TC 23-80 was the first of only two significant tropical cyclones in 1980 (TC 23-80 and TC 27-80) to occur over the northern Indian Ocean. It developed during the autumn transition season just prior to the north-east monsoon period. Orginating as an area of enhanced convection in the monsoon trough off the south-west coast of India, TC 23-80 tracked steadily north-westward over the Arabian Sea between 12 and 17 November.

On 17 November, a mid-tropospheric trough tracking eastward toward India began to induce TC 23-80 to recurve to the north-east. The main area of convection and the associated low-level centre did indeed begin to recurve. However, satellite imagery evaluated during the post-analysis indicates that a second low-level circulation formed south-west of TC 23-80 on 17 November. The first circulation continued north-eastward and dissipated near the Indian coast, while the secondary circulation continued moving westward as a well-defined, exposed, low-level circulation. This secondary circulation eventually weakened and dissipated on the coast of Saudi Arabia, five days after cyclogenesis.

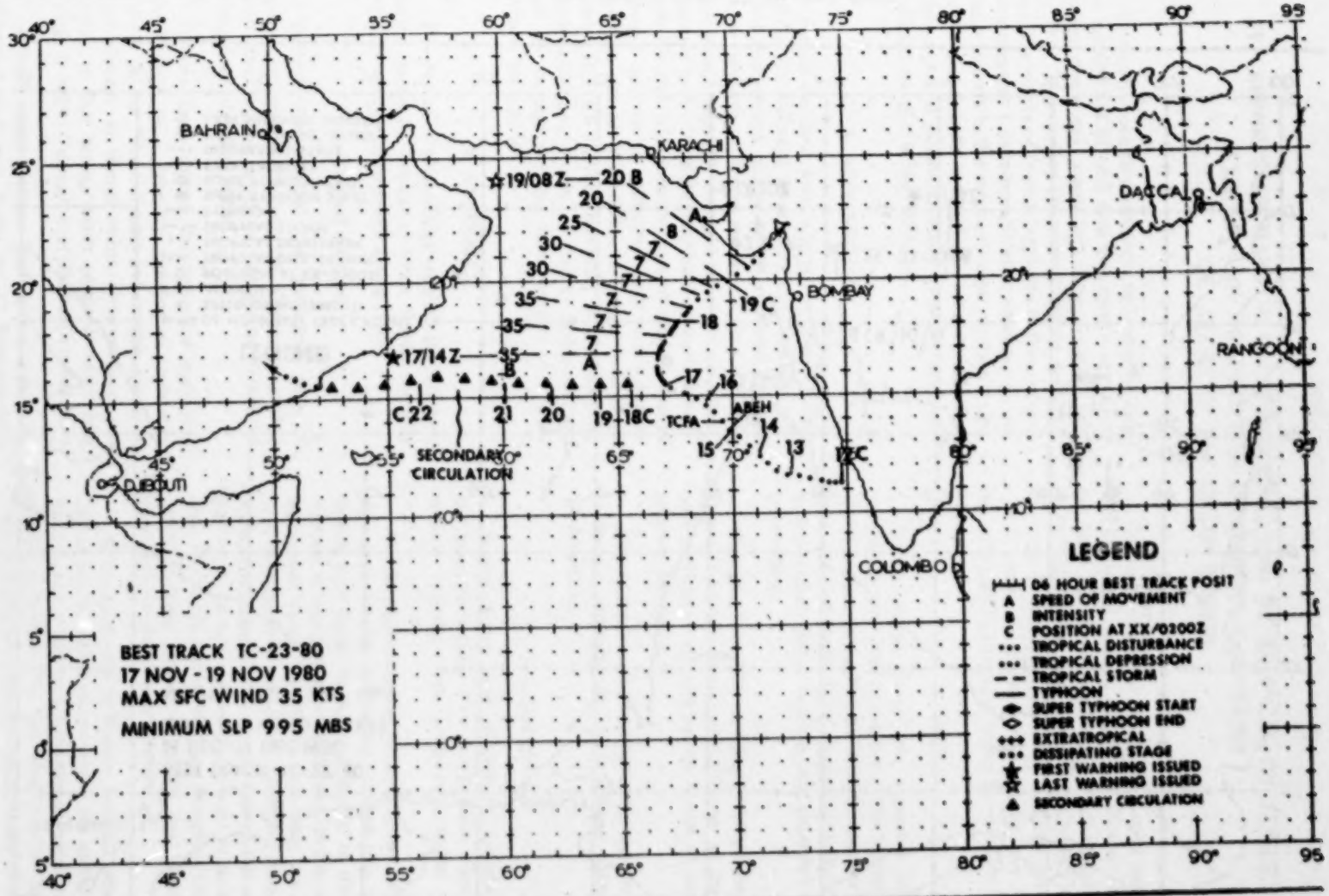


Figure 23. Tropical Cyclone 23-80, best track

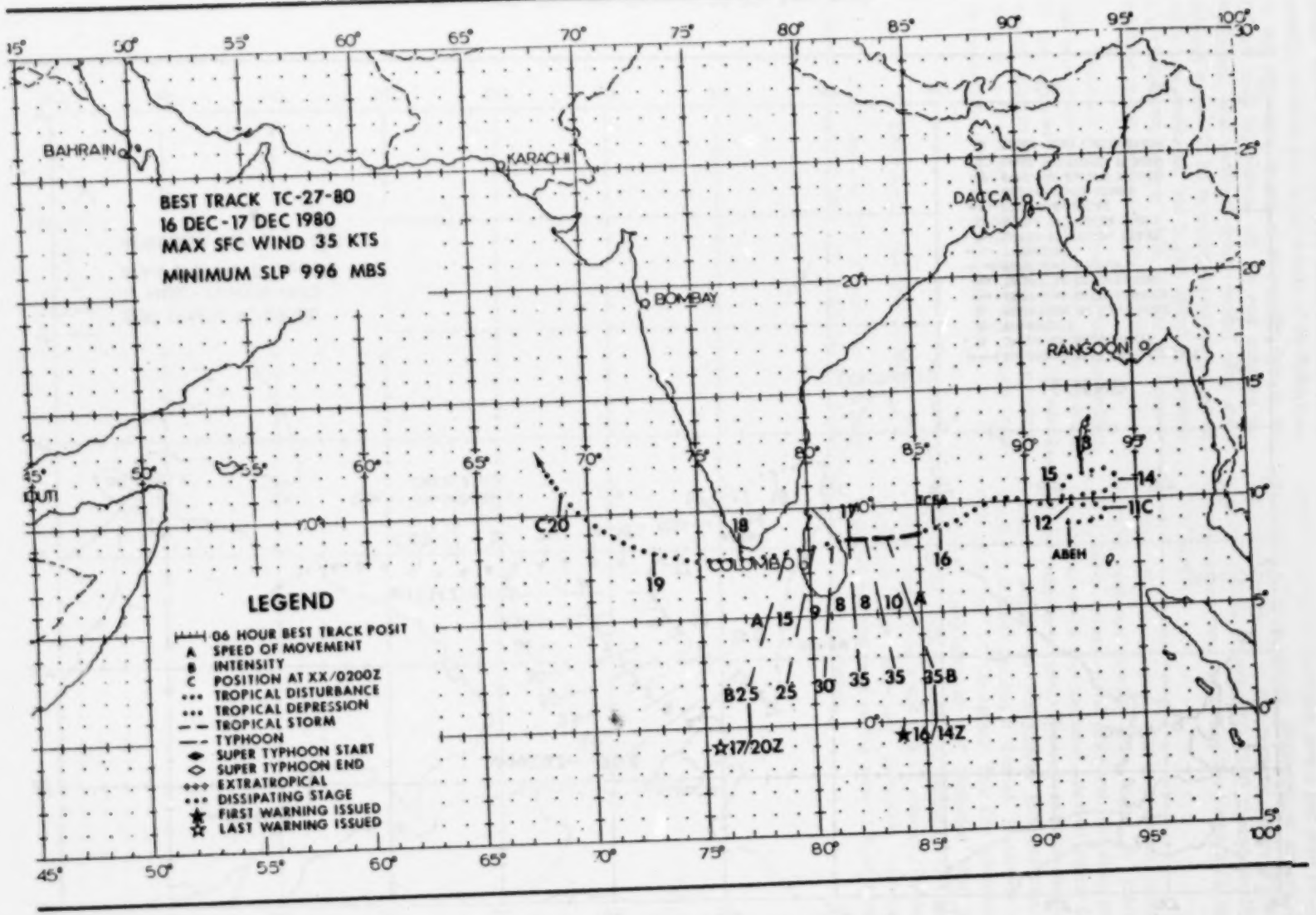


Figure 24. Tropical Cyclone 27-80, best track
(no narrative available on this cyclone)

IV. REPORTS OF DAMAGE CAUSED DURING 1980 BY TROPICAL CYCLONES, FLOODS AND DROUGHTS IN INDIVIDUAL COUNTRIES OR AREAS IN THE ESCAP REGION

Individual countries, territories and other entities have supplied ESCAP with their own reports on meteorological events and consequent damage during the year 1980. These reports are presented in the following pages. The variety of formats employed in these reports does not permit a definitive statistical statement on the damage incurred in the region. However, we have drawn together the episodic data as reported and present in table 4 a general picture of damage caused by cyclones, floods and droughts in the region.

A. AFGHANISTAN

Figures for land areas affected by floods during 1980 in the Helmand River valley and details of estimated flood-related damage in this area were reported by the Ministry of Water and Power (see table 5). Land areas completely damaged or otherwise affected amounted to 30,724 jeribs, equivalent to approximately 6,000 hectares. The estimated cost of rehabilitation of damaged farmhouses, cultivated lands and hydraulic structures was Af 293 million, equivalent to approximately $US 6.6 million, according to the Ministry. Nearly 4,000 people were affected by floods over the year. No damage resulting from drought or tropical cyclones was reported.

B. AUSTRALIA

The Bureau of Meteorology reported the following damage caused by tropical cyclones, floods, droughts and other severe weather events during 1980.

1. Tropical cyclones

Cyclone Amy crossed the north-west coast at Pardoo, east of Port Hedland, on 10 January, causing about $A 7 million worth of damage, mostly at the mining town of Goldsworthy.

Cyclone Dean crossed the north-west coast near Port Hedland on 1 February, flooding all major river systems in the Pilbara district and causing wind and water damage in several towns. Cyclone Dean was unusual in that strong winds persisted inland long enough to buffet Newman, over 300 km from the coast.

A third major cyclone, Enid, moved across the north-west coast near Wallal on 17 February with wind gusts estimated up to 225 km/h. All 20 buildings at Wallal were destroyed, the town of Shay Gap was severely battered and there were heavy stock losses.

Five other cyclones threatened coastal areas but caused minimal damage. These were Paul in January, and Ruth and Simon in February, which brought gales to parts of the east coast; Brian, which formed just off the coast in the Timor Sea on 20 January but which moved away; and Doris, which affected the Arafura Sea and Gulf of Carpentaria during the middle of March.

2. Floods

In Queensland, heavy rain associated with the incipient cyclone Paul caused one of the highest floods of this century in the Don River catchment near Bowen on 6 and 7 January. Total damage, including damage to the market garden industry, was estimated at over $A 4 million.

Widespread flooding resulting from cyclones Amy, Dean and Enid in January and February in the north-west of Western Australia caused closure of roads and property damage.

During June, severe flooding in the Carnarvon area of Western Australia resulted in damage estimated at $A 4.5 million.

3. Droughts

Several States were affected by drought during the year, particularly New South Wales where many stations recorded their lowest-even annual rainfall.

For the eight-month period of February to September, severe rainfall deficiencies occurred over much of eastern New South Wales, extending far to the east of Victoria. A large number of stations in this area recorded less rainfall during February to September than for the same eight-month period in any other year since records commenced (generally about the start of this century). Rainfall in December eased the drought in parts of this area, but at the end of the year drought continued to persist in many districts of eastern New South Wales. Stock and crop losses were extensive.

In the south-west of Western Australia, where most of the year's rainfall occurs during the period of May to October, a large area experienced severe or serious rainfall deficiencies. In this area, May to September were generally the driest five months since 1914. Severe rainfall deficiencies continued in agricultural districts of the south-west during the remainder of the year, resulting in crop losses.

Table 4: Damage suffered in selected Asian and Pacific countries during 1980 from natural disasters: flood, drought and tropical storms

	Type of natural disaster	Area affected (1,000 ha)	Population affected	Casualties		Houses or buildings		Agricultural crops, land damaged ($US million)[a]	Livestock lost (head)	Private property and public utilities damaged ($US million)	Total estimated damage ($US million)		Exchange rate per $US 1.- (local currency units)[b]
				Dead or missing	Injured	Destroyed	Damaged				Per type of disaster	Total	
Afghanistan[c]	Floods	6.0	3 963			-------1 975-------		2.3		3.6[d]	5.9	5.9	44.5
Burma	Floods	241.0								0.7	0.7	2.1	[e]
	Rainfall deficiency	875.9											
	Cyclones									1.4	1.4		
Hong Kong	Drought							[f]63 475 trees in plantations[g] [f]400 ha[g]					
	Hailstorms		300										
	Cyclones			6	59								
India	Floods	11 421.1	54 092 145	1 903		---2 530 936-------		469.2[f]	59 401	594.9[g]	1 063.7	1 063.7	7.803
Japan	Typhoons	0.1		55	94	9	5 643						
	Heavy rainfall	6.6		33	55	81	33 560						
Malaysia	Floods	1 312	8 701	3	2						1.5	1.6	2.19
	Drought										0.1		
Philippines	Flood		[h]1 422 428	128		6 860	42 927	112.2		53.3[h]	165.5	350.2	7.5805
	Cyclones		[i]3 200 families[j]	172	55	16 066	48 536	116.4		68.3[i]	184.7		
Thailand	Floods	927.9	831 368	61	7	2 394		47.6		9.3	75.1[k]	75.1	20.395
Trust Territory of the Pacific Islands	Typhoon					60	214				7.0	7.0	
Viet Nam	Cyclones, floods	1 564.2	10 000 000	496	384	933 339	103 934		tens of millions				

Sources: Official communications from the countries concerned. See country reports on the following pages for full reports.

Notes: The data in this table are drawn from the country reports in this *Journal*. Estimates of damage in monetary terms are given in current values.

a/ In some cases, figures for agricultural damages are given in other than monetary terms (indicated in parentheses in such cases).

b/ Exchange rates for United States dollars, published in *International Financial Statistics*, vol.xxxiv, No. 1 (January 1981), are utilized where estimates of damage in the country concerned were given to ESCAP in local currency units.

c/ Estimates for Afghanistan apply to the Helmand River valley area only.

d/ Official estimates of property damage in Afghanistan comprise estimated costs of rehabilitating damaged hydraulic structures and housing units, and replacing lost fertilizer.

e/ Cost-equivalents of estimated damage were supplied in United States dollar figures by the Burmese Government.

f/ Area of cropland damaged by floods in India was about 5.5 million ha.

g/ Estimates of private property and public utilities damaged in India consist of official estimates of damage to houses and public utilities.

h/ The flood damage estimate in this category in the Philippines derives from damages to public property, private property, roads, bridges and public works.

i/ The cyclone damage estimate in this category in the Philippines derives from damages to roads, bridges, private and public buildings and properties, "infrastructure", public works and one instance of "crops", which was given as part of a lump sum for all damages inflicted by Typhoons Kitang and Osang (see country report).

j/ The total reported damage from floods in Thailand includes items not covered in this table; hence the total reported is greater than the sum of the items mentioned in the table.

Table 5. Estimates of flood damage in the Helmand River valley, Afghanistan, during 1980

Areas affected	Population affected	CATEGORIES OF PROPERTY DAMAGED						
		House units	Bags of fertilizer	Land areas completely damaged (J)	Other land areas affected			
					Crop lands (J)	Vineyards, orchards (J)	Uncultivated lands (J)	Non-irrigated lands (J)
Grishk	814	133	3 743	1 621	2 887	12	3 036	57
Nadi-Ali	16	-	107	36	101	-	105	-
Marja	240	46	2 527	-	2 505	9	-	-
Lashkar	430	90	2 732	-	2 273	-	8	-
Shamalan	805	503	2 692	1 147	2 915	17.5	679	46.5
Darveshan	1 250	970	5 017	920	6 172	17	356	19
Khansheen	408	233	-	-	4 833	-	832	120
Totals	3 963	1 975	16 818	3 724	21 686	55.5	5 016	242.5
Estimated costs of rehabilitation* (Af)		49 375 000	8 801 420	18 620 000	95 418 400	555 000		485 000

Source: Official communication to ESCAP from the Department of Planning, Ministry of Water and Power, Government of Afghanistan.

Notes: Areal units: jerib (1 J= 0.19536 hectare). Currency: afghani (1 Af = $US 0.02; $US 1 = 44.5 Afs).

* As tabulated here, the estimated cost of rehabilitation of lands completely damaged or otherwise affected, house units and fertilizer is Af 173,254,820. The total estimated cost of rehabilitating the damages sustained, including hydraulic structures, is reported at Af 293 million.

4. Other severe weather events

Gale-force winds in mid-March over much of southern Tasmania resulted in losses to the apple crop estimated at $A 1 million, and caused damage to property and power failures.

Gale- to storm-force winds in south-eastern Australia during 27 to 29 June caused three deaths. In New South Wales damage was estimated at $A 1 million. This area was severely buffeted twice more, between 30 and 31 August and 9 and 10 September, when two further deaths occurred. Damaging gale-force winds were again experienced on 15 September.

Thunderstorms and tornadic squalls caused at least $A 10 million damage in Brisbane on 16 December. Over 5,000 houses were damaged and a number of aircraft overturned at Archerfied Airport.

C. BURMA

Details of damages caused by floods, rainfall deficiency and cyclones during 1980 are given in table 6. No loss of human life or cattle from these natural disasters was reported for the year.

Table 6. Damages caused by floods, rainfall deficiency and cyclones in Burma during 1980

Floods		*Rainfall deficiency*	*Cyclones*
Area damaged (ha)	*Cost-equivalent of damage to roads, bridges, other structures ($US million)*	*Area damaged (ha)*	*Cost-equivalent of damage to structures ($US million)*
240 957	0.68	875 862	1.36

Source: Official communication to ESCAP from the Department of Meteorology and Hydrology, Ministry of Transport and Communications, Government of Burma.

D. FIJI

The Fiji Meteorological Service, in its *Technical Note No. 13,* has described in summary form the development and characteristics of three tropical cyclones affecting Fiji during the early part of 1980. These descriptions have been extracted for this issue of *Water Resources Journal,* together with diagrams of the storm-tracks (figures 25 to 27).

The 1979-1980 cyclone season

(a) *Peni (2-5 January 1980)*

Generally disturbed weather about Tuvalu and Rotuma as early as 31 December 1979 suggested possible cyclone development. By about midday on 2 January 1980, a depression lay about 300 mi west-northwest of Rotuma, or near 11°S, 173°E, moving east-southeast directly towards Rotuma at about 10 kn (see figure 25). By midnight it had slowed down slightly and begun to move south-east, evolving into Tropical Cyclone Peni, with maximum sustained winds estimated at around 40 kn. During the night it turned steadily south. By 3 a.m. it was centred about 150 mi west of Rotuma and was moving southward at just over 5 kn.

Through the next 15 hours or so Peni moved almost due south, doing a slight leftward curve in its track and intensifying steadily. By 3 p.m. on 3 January, maximum winds near its centre were estimated to have reached storm intensity (over 47 kn). From then on Peni accelerated rapidly, intensified further, and for the rest of its life continued to turn steadily more and more eastward in its track.

At about 8 a.m. on Friday, 4 January, Peni was centred about 150 mi west of Yasawa-i-rara, moving south-southeast at about 15 kn, with maximum winds estimated at around 65 kn. Its centre passed about 60 mi south-west of the Mamanutha Group and 80 mi off Nandi between 3 and 4 p.m., moving at about 20 kn. It was at its peak intensity of just over 65 kn at this stage, and underwent spectacularly rapid weakening thereafter.

By 9 p.m. on Friday, Peni was centred about 60 mi south-west of Vunisea in Kandavu, moving south-east at about 25 kn, with maximum sustained winds of around 50 to 55 kn. By about midmight on Friday, it was moving eastward at about 20 kn, continuing to weaken rapidly. By midday on Saturday, 5 January, Peni had degenerated into a depression with maximum winds below gale force, and lay centred about 20 mi north of Ono-i-Lau.

(i) Winds

Peni apparently just attained hurricane intensity. Since it did not move close to any land area, intensity estimates were based almost entirely on satellite information.

At noon on 2 January, a depression with maximum sustained winds estimated at about 25 kn was evident from satellite imagery. Satellite interpreters in Honolulu suggested a tropical cyclone with maximum winds of around 45 kn by 4 a.m. on Thursday, 3 January. Peni continued to intensify steadily. By 10 p.m. on Thursday the estimated maximum wind was around 55 kn, and by 2 a.m. on Friday about 60 kn. From 2 a.m. to 4 p.m. on Friday, satellite imagery estimates continued to yield 65 kn. Thereafter rapid weakening occurred; by 10 p.m. maximum winds appear to have been about 55 kn, and by 4 a.m. they had dropped to less than 35 kn. Castaway Island in the Mamanutha Group experienced winds estimated at 35 to 40 kn at about 3.30 p.m. Nandi Airport recorded maximum sustained winds of 33 kn at 3.30 p.m. and 4.10 p.m., with a maximum gust of 47 kn.

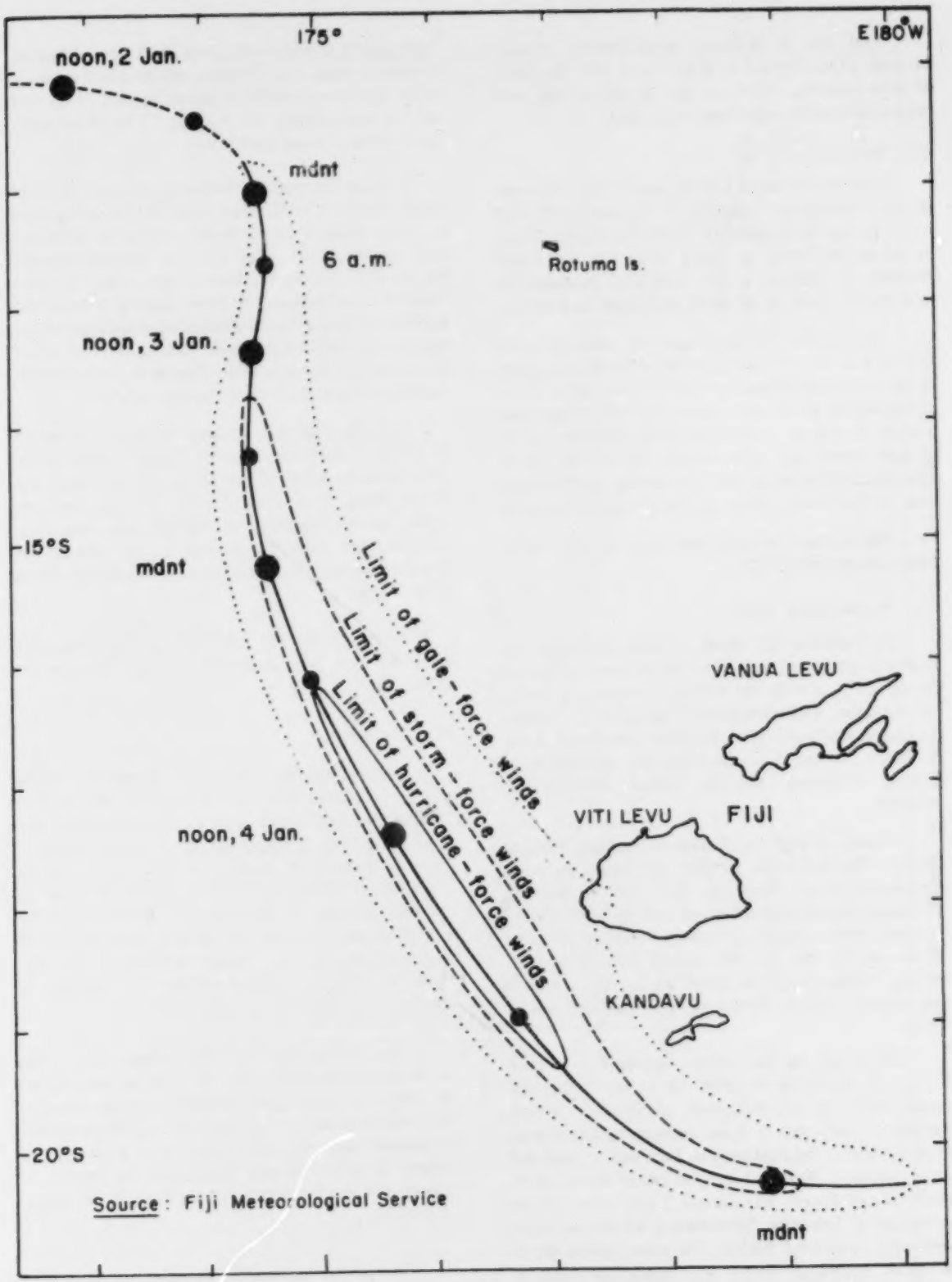


Figure 25. Track of Tropical Cyclone Peni, 2 – 5 January 1980

Peni was a relatively small-diameter cyclone; at most, gales extended to about 70 mi from the centre at peak intensity. Winds on the left side of the track were somewhat stronger than on the right.

(ii) Summary

Peni passed about 150 mi west of Rotuma early in the morning of Thursday, 3 January 1980, and about 60 mi west-southwest of the Mamanutha Group or 80 mi off Nandi on Friday afternoon. By Friday evening, 4 January, it had weakened substantially, and passed about 60 mi south of Vunisea in Kandavu.

The cyclone had hurricane-force winds (over 63 kn) for just over 12 hours. Satellite information suggests it had maximum sustained winds of about 65 to 70 kn at its peak. It was a small system and did not pass close enough to Fiji or maintain intensity long enough to produce more than gales in any part of the Group. The Mamanutha Group, and the extreme south-western area of Viti Levu, appear to have experienced gales.

The cyclone brought some relief in the form of rain to many parts of Fiji.

(b) *Tia (24 March 1980)*

On Saturday, 22 March, a small depression was evident in the area about 150 to 200 mi west of Rotuma, around 12°S, 174°E. By Sunday morning the system had maximum winds estimated at about 35 kn, without any perceptible movement. Towards Sunday afternoon, 23 March, the centre of the depression appeared to be drifting southward, but no further intensification occurred.

During the night of Sunday to Monday, Tropical Cyclone Tia intensified steadily and began to move south-eastward (see figure 26). By 5 a.m. on Monday, 24 March, Tia was centred about 140 mi north-west of Lambasa, with estimated maximum sustained winds of 50 kn. By 11 a.m. Tia was centred close to Dreketi, moving south-eastward at about 15 kn. By 1 p.m. it was centred close to Savusavu, with winds of around 55 kn.

From then on the cyclone appeared to weaken slowly. It continued to speed up in movement, and passed about 10 mi south-west of Vuna in Taveuni between 2 p.m. and 3 p.m., moving south-eastward at about 20 kn. Tia continued to turn slowly more and more eastward. Around 5 p.m. it passed about 10 mi north-east of Mango, and around 7 p.m. about 20 mi north-east of Lakemba. Subsequently Tia alowed down somewhat, weakened further, and passed about 20 mi north of Haapai in Tonga, with maximum winds of around 30 to 40 kn.

(i) Winds

On Saturday, 22 March, all satellite estimates of maximum sustained winds were 30 kn. At Rotuma itself the winds were round 15 kn. By 8 a.m. on Sunday, 23 March, some intensification appeared to have taken place. Satellite estimates continued to yield 35 kn until early in the evening. At Rotuma, 15 to 25-kn north-westerlies were being experienced.

During the night of Sunday to Monday, 23 to 24 March, steady intensification occurred, and interpreters at Nandi Airport and Honolulu estimated maximum sustained winds of 50 kn early on Monday morning. By the time Tia reached the northern coast of Vanua Levu, it was estimated to have attained a maximum intensity of about 55 kn. Weather stations reported the highest sustained wind speeds, ranging between 30 kn (Lambasa, 1 p.m.) and 55 kn (Savusavu, 1 p.m.) as the cyclone moved across Fiji on Monday, 4 March.

Reports of damage appeared consistent with speeds of 55 kn, corresponding to the "storm" category, i.e. with sustained winds of over 47 kn but not more than 63 kn. Some local concentration of wind flow over ridges, around headlands or through gaps may have occurred, and some places close to the path of the cyclone may have been sheltered from the full effects of the winds.

Winds on the left hand side of the storm were likely to have been somewhat stronger than on the right.

(ii) Summary

Tropical Cyclone Tia moved across the central portion of Vanua Levu around noon on Monday, 24 March 1980, and passed close to the west of Savusavu at about 1 p.m. It passed about 10 mi south-west of Vuna in Taveuni at about 2.30 p.m., about 10 mi north-east of Thithia at around 5 p.m. and 20 mi north-east of Lakemba at about 7 p.m. Subsequently Tia moved almost east-southeast, slowed down somewhat, weakened steadily and passed between Haapai and Vavau in Tonga at around midday on Tuesday, 25 March.

The cyclone gave storm-force winds (over 47 kn) for a time to places in a strip 40 to 50 mi wide. It does not appear to have quite reached hurricane intensity (i.e. with sustained winds over 63 kn). Measurements at stations near its path, assessments from satellite imagery at Honolulu and Nandi and the reports of damage put the maximum sustained winds at around 55 to 60 kn.

Tia's passage through the Savusavu area coincided with high tide and caused a moderate storm surge. The configuration of the coast of Savusavu Bay presumably added to the effects. The cyclone developed steadily as it approached and move across Fiji. Forecasts of winds, rain and coastal sea flooding (at high tide) proved correct.

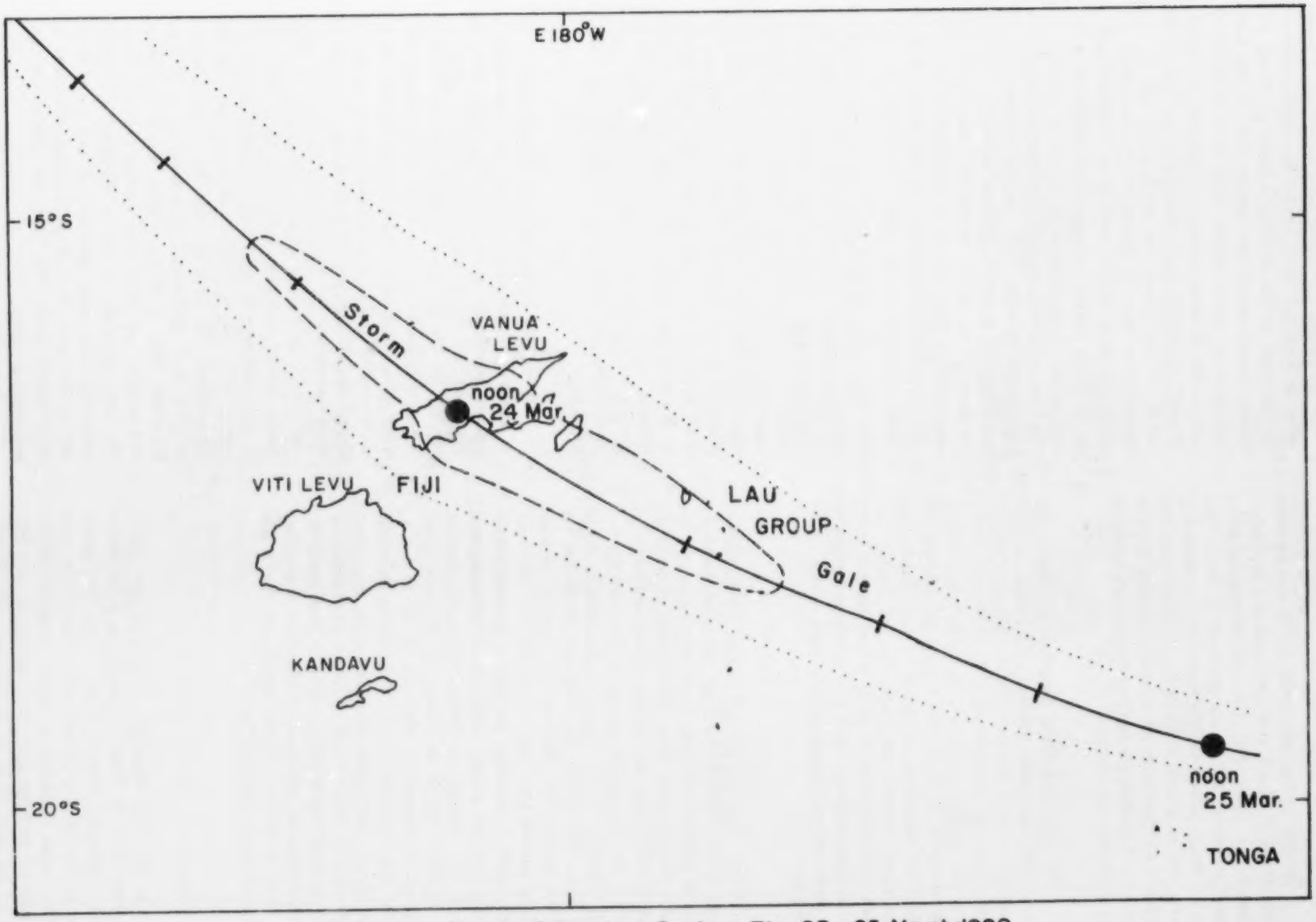


Figure 26. Track of Tropical Cyclone Tia, 23 – 25 March 1980

(c) *Wally (3-5 April 1980)*

Weather in the area north of Fiji was disturbed from about 31 March to 4 April, and two depressions formed (see figure 27). The first depression, which developed about 100 mi east-northeast of Undu Point on 31 March, moved steadily westward at a distance of about 100 to 150 mi north of Fiji. Another depression began to develop about 150 mi north-northeast of Undu Point on 1 April as the first depression moved away to the north-west and weakened.

This latter depression deepened very slowly and moved quite irregularly during 1 and 2 April, doing a clockwise loop in the area 100 to 150 mi north of Undu Point. By midnight on 2 April, it was centred about 80 mi north-northwest of Undu Point, moving west-southwest at about 4 kn. During the following 36 hours the depression continued to slow down, turn increasingly towards the south-west and deepen very slowly. By midday on 4 April, it was centred about 90 mi north-northeast of Yasawa-i-Rara and about 80 mi north-west of Labasa, drifting south-west at about 1 to 2 kn.

From about midday on Friday the depression started to turn towards the south and move faster. By noon on Saturday, 5 April, it was centred east of the Yasawa Group, about 20 to 30 mi north of the north coast of Viti Levu, and moving almost southward at about 8 kn. During the afternoon and evening of 5 April, Cyclone Wally's centre moved steadily across Viti Levu. The cyclone had deepened slowly but had still not acquired the character of a tropical cyclone. After it crossed Viti Levu and moved into the open ocean, which presumably contributed towards intensification, satellite imagery early on 6 April suggested that it was beginning to become a tropical cyclone. The reporting station in Vunisea in Kandavu Island estimated north-westerly winds of 37 kn at 4 a.m., 5 a.m. and 6 a.m. on 5 April. (The station is located on an isthmus with higher ground on either side, where north-westerly winds would undergo some concentration.) As Wally moved farther south, it came under the inhibitive shearing influences of the upper troposphere and failed to achieve an intensify greater than a gale (sustained winds of 34 to 47 kn).

(i) Winds

As the first depression developed and moved westward from 31 March onwards, a moist south-easterly airstream covered most of the Fiji group. Areas of Viti Levu to the east and south of the main dividing ranges continued to receive moderate rainfall, although no well-organized cloud system lay over Fiji. Falls of the order of 30 to 50 mm were recorded over the Rewa and Navua River catchments for the 24 hours ending at 9. a.m. on 1 April.

By midday on 1 April, when Wally had its beginning, an organized cloud system lay almost east-west to the south of Fiji, overlying a low-level easterly airstream. South-eastern and eastern parts of Viti Levu continued to receive rainfall of the order of 30 to 60 mm in the 24 hours ending at 9 a.m. on Wednesday, 2 April. By midday on 2 April the system had shifted north, covered almost the whole group and lay embedded in a deep south-easterly airstream from the surface upwards. Available records of rainfall at stations in the Rewa catchment ranged from around 40 to 160 mm in the 24 hours ending at 9 a.m. on 3 April. For the same period the rainfall in the Navua catchment was considerably heavier, with available records showing a range of about 140 to 270 mm. During the following 36 hours or so, rainfall became very heavy. Although the centre of Wally lay well to the north of Viti Levu and drifted south-westward, the associated band of cloud and rain continued to affect the island.

The south-easterly airflow in the lowest layers of the atmosphere in the area of the cloud system over Viti Levu began to increase. By 3 April, south-easterly winds at 3,000 ft over Nandi Airport (taken to represent windflow over Viti Levu) had increased to 35 kn, and those at 5,000 ft had increased to around 50 kn. This situation persisted through 4 April. From then on, the wind began to turn more easterly and north-easterly as the depression centre approached Viti Levu. The stronger winds on 3 and 4 April, blowing over the gradually rising topography, contributed towards intensified rainfall over eastern and particularly south-eastern Viti Levu.

By midday on 3 April, the system covered all of Fiji except the eastern Vanua Levu and Taveuni area. In eastern and south-eastern Viti Levu, including the Rewa and Navua catchments, available records of rainfalls for the 24 hours ending 9 a.m. on 4 April, ranged from about 200 to 400 mm. In comparison with other areas, somewhat heavier falls were recorded about south-eastern Viti Levu, including the Navua catchment. Heavy rainfall continued on 4 April. As the centre of Wally approached the Yasawa group on a south-south-west track, the western edge of the associated cloud system moved westward across Viti Levu. By about 6 p.m., rainfall over most parts of south-eastern and eastern Viti Levu had eased. Falls over most of the north-eastern Viti Levu area for the 24 hours ending at 9 a.m. on 5 April ranged from about 80 to 200 mm. Elsewhere, falls for the same period ranged from about 200 to 650 mm. For a large portion of south-eastern Viti Levu, especially the Navua, Waidina and Waimanu catchments, the range appeared to have been about 400 to 650 mm. On 5 April, although the centre of Wally moved across Viti Levu, the rainfall amounts were relatively small.

Two factors appeared to have retarded the development of Wally into a tropical cyclone as it moved

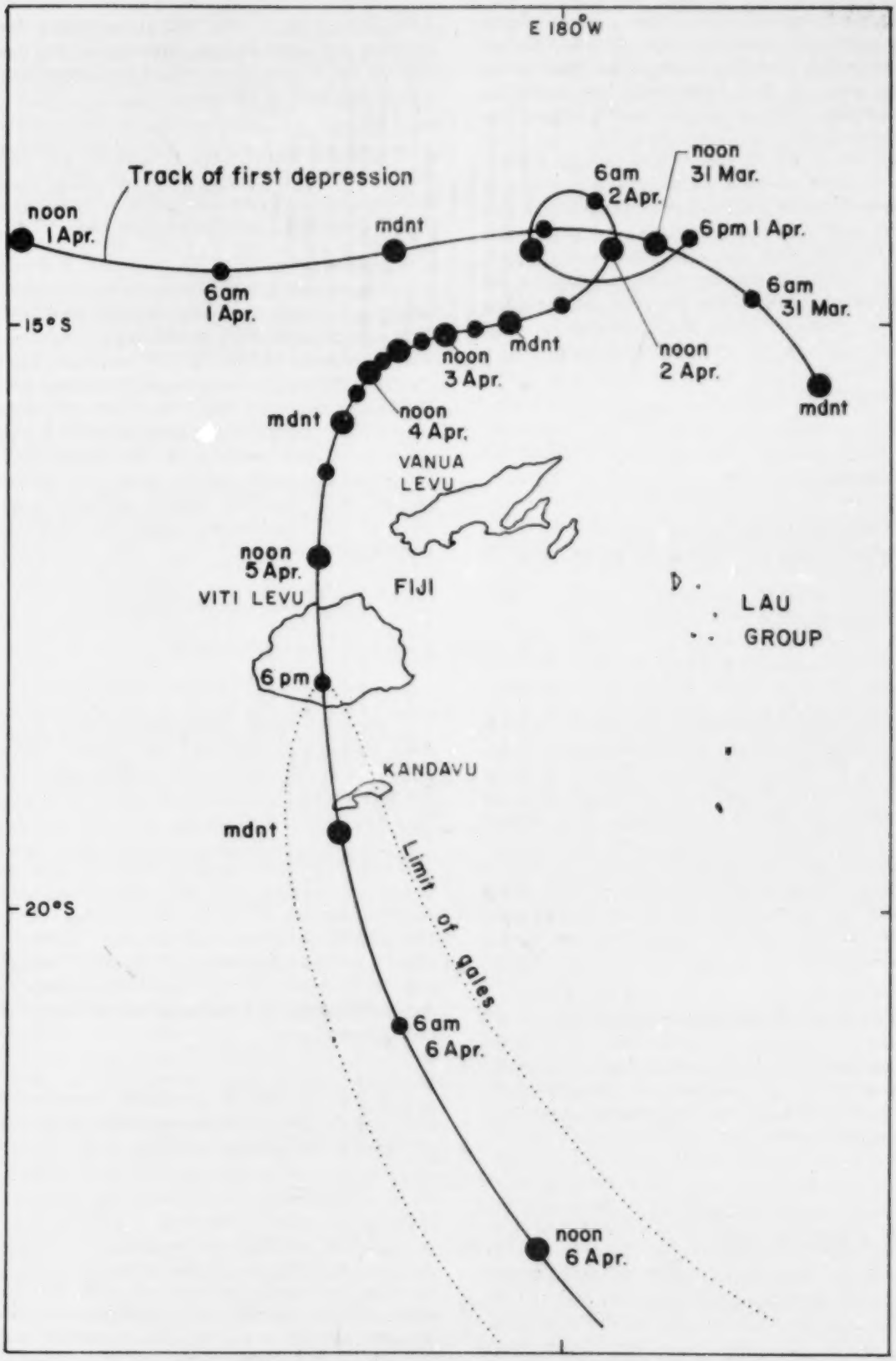


Figure 27. Track of Cyclone Waily, 1–6 April 1980

slowly in the area north of Fiji. Wally moved very slowly while crossing the track traversed by Cyclone Tia about a week earlier. Upwelling in the surface layers of the ocean caused by Tia's winds would have cooled the ocean surface, which in turn would have slowed down the intensification of Wally. Secondly, while Wally moved very slowly for four days in the area north of Fiji, the main rain-band associated with it continued to cover Viti Levu. The relatively heavy rainfall over eastern and south-eastern Viti Levu, in comparison with that over other areas, shows that the island intercepted a substantial amount of the moisture from the south-easterly airstream and the cloud system feeding into the centre of Wally. If this moisture had been released closer to the centre of Wally, intensification into a tropical cyclone could have occurred more rapidly and before it crossed Fiji.

(ii) Summary

During the period in which Cyclone Wally moved slowly in the area north of Fiji and passed across Viti Levu, from 1 to 5 April 1980, it remained a deep, extensive and active tropical depression. It may have had tropical cyclone characteristics for a short period after passing south of Viti Levu.

A narrow coastal strip of southern Viti Levu, Vatulele, Mbengga, Kandavu and other smaller islands in the general area experienced gale-force winds around 35 kn on the evening and night of 5 to 6 April.

Damage was entirely due to the prolonged heavy rain. Partly because of its very slow movement in the area north of Fiji, Wally caused heavy rainfall over the south-eastern half of Viti Levu east and south of the main dividing mountain ranges. Consequent severe flooding of the Navua River, Rewa River and several other smaller coastal rivers was accompanied in many places by massive landslides. On the basis of rainfall data, the more severe flooding would have occurred in the Navua, Waimanu, Waidina and other smaller rivers draining south-eastern coastal Viti Levu from about Korolevu eastward.

E. HONG KONG

The Royal Observatory in Hong Kong reported the following information on damage caused by tropical cyclones, floods and droughts in Hong Kong during 1980. The principal sources of information were the Agriculture and Fisheries Department, Fire Services Department, Public Works Department, Social Welfare Department and the Royal Observatory, as well as the press. Damage to private property, which is seldom reported, was not included, nor was any attempt made to estimate the number of working hours lost because of bad weather.

1. Drought and low rainfall

The year 1980 was generally hot and dry. Rainfall was only 1,710.6 mm, compared to a normal annual rainfall of 2,246.4 mm. No water supply restrictions were imposed, however.

The total rainfall for October 1979 to January 1980 amounted to only 15.7 mm, making this the driest four-month period ever recorded. There were only 12 days with measurable rain in June 1980, which set a new record for the month. The total rainfall for June was 150.9 mm (which is 306.6 mm below normal); This made it the tenth lowest on record for the month. August was also dry, and the month's total rainfall of 250.0 mm was 170.2 mm below average. The last four months of the year were all drier than normal. There was a prolonged fine spell from 29 September until 17 October. The only day with measurable rain was 7 December, and the month's total rainfall was only 0.7 mm.

Because of the dry conditions, numerous hill fires broke out and destroyed more than 60,000 trees, as reported in the following table.

Grass and hill fires in 1980	*Jan-Mar*	*Apr-Jun*	*Jul-Sep*	*Oct-Dec*	*Total*
Number of grass or hill fires	138	69	12	626	845
Number of trees damaged or destroyed within plantation/management areas	50 780	1 125	100	11 470	63 475

2. Heavy rainfall, hailstorms and floods

Although the year was comparatively dry, hail was reported on three occasions in February and March. The first occasion was associated with the passage of a cold front early on the morning of 27 February, accompanied by thunderstorms and violent north-westerly squalls. Hail, which had never been recorded in February in Hong Kong before, was reported by a number of people residing in the Kwai Chung and Repulse Bay areas. The next two occasions were on 5 and 6 March. This set a new record of three hail-storms in nine days. On 5 March, residents in Yuen Long, Kam Tin, Tuen Mun, Tsuen Wan, Tai Mo Shan and Tai Po reported hail between 12.05 p.m. and 12.45 p.m. The biggest hailstones measured about 30 mm in diameter. About 400 hectares of crops, representing 12 per cent of Hong Kong's total vegetable production, were damaged by the hail. Hail was reported again shortly after 5.00 a.m. on 6 March at Kam Tin, Lam Tsuen and Yuen Chau Tsai.

In August, thunderstorms and heavy rain on 7 August led to serious flooding in Tsuen Wan and Kwai Chung. The flooding held up traffic for some hours. About 300 people were evacuated from their homes. A minor landslip occurred near the railway in Sha Tin.

3. Tropical cyclones

The number of tropical cyclones over the western North Pacific and the China Seas was nearly normal. Signals were hoisted on 10 occasions, including seven on weekends. None of the storms came very close to Hong Kong, however, and winds only once reached gale force for a few hours during Typhoon Joe. The following paragraphs describe the 10 occasions during 1980 when tropical cyclone warning signals were issued.

(a) *Severe Tropical Storm Georgia (19-25 May)*

Georgia first developed early on 19 May as a tropical depression on the remains of a cold front about 400 naut mi south of Hong Kong, and remained quasi-stationary during the next two days. Georgia then established a northerly course towards the South China coast. In Hong Kong the stand-by signal, No. 1, was hoisted at 11.45 a.m. on 22 May, when Georgia was about 340 naut mi to the south-southeast. When Georgia came closer, the strong wind signal, No. 3, replaced the stand-by signal at 11.45 a.m. on 23 May. Georgia became a severe tropical storm during that afternoon, and moved north-northeast towards Shantou. It was closest to Hong Kong around 11 p.m., when passing about 90 naut mi to the east-southeast. In Hong Kong, winds were moderate easterly on 22 May, but gradually freshened from the north-east during the night and became strong during the following morning. Gales were experienced off shore and on hill tops during the afternoon of 23 May. Winds weakened during the night, however, and turned to south-westerly the following day. In Hong Kong, all signals were lowered at 5.45 a.m. on 24 May as Georgia crossed the coast of South China near Shantou, about 110 naut mi east-northeast of Hong Kong. During the approach of Georgia, damage in Hong Kong was minimal. Apart from some scaffolding partly blown down by strong winds, no other incidents were reported. Only 15.3 mm of rain were recorded in Hong Kong.

(b) *Severe Tropical Storm Herbert (24-28 June)*

Herbert originated as a tropical depression about 650 naut mi south of Hong Kong on 24 June. At first it moved rapidly west-northwest at about 17 kn towards north Viet Nam, but gradually it changed to a north-westerly course and slowed down to about 10 kn during the following day. Herbert intensified into a tropical storm early on 25 June. As Herbert was still coming closer to Hong Kong, the stand-by signal, No. 1, was hoisted at 7.35 a.m. on 26 June, when its centre was about 350 naut mi to the south-southwest. Then Herbert intensified further into a severe tropical storm and moved towards Hainan. Herbert was closest to Hong Kong around 2.00 a.m. on 28 June, after crossing the island. At the time of closest approach, the centre of Herbert was about 300 naut mi to the west-southwest. Finally, Herbert crossed the coast about 110 naut mi east-northeast of Hanoi. In Hong Kong winds were moderate easterly on 25 June, but, with the approach of Herbert, fresh to strong south-easterly winds were experienced in exposed places during the following three days. In Hong Kong all signals were lowered at 11.30 a.m. on 28 June. During the approach of Severe Tropical Storm Herbert, damage in Hong Kong was minimal. However, two men on board a commercial helicopter were killed when the helicopter crashed into the slopes of Tai Mo Shan in the afternoon of 27 June. The showers on the morning of 29 June flooded some roads and caused a few minor landslips. A total of 82.7 mm of rain was brought by Herbert from 25 to 29 June.

(c) *Severe Tropical Storm Ida (5-12 July)*

Ida formed about 240 naut mi south-west of Guam on 5 July. It set out on a west-northwesterly course towards the Bashi Channel during the following four days, and intensified into a severe tropical storm early on 7 July. After crossing the Bashi Channel, Ida slowed down as it entered the South China Sea. In Hong Kong, the stand-by signal, No. 1, was hoisted at 6.00 a.m. on 10 July when Ida was about 390 naut mi east-southeast of Hong Kong. Early on 11 July, Ida took a north-westerly course towards Shantou at about 7 kn. It made its closest approach to Hong Kong around 8.00 p.m. on 11 July, when the centre was about 150 naut mi to the east-northeast. Ida landed near Shantou in the afternoon of 11 July. In Hong Kong, winds were moderate westerly on 9 to 10 July. As Ida moved closer to Hong Kong, winds began to freshen on 11 July and were strong off shore at times during the night. All signals were lowered at 6.10 a.m. on 12 July, when Ida was

overland about 160 naut mi north-east of Hong Kong. Winds turned south-westerly and abated in the evening on 12 July. A total of 190.8 mm of rain was recorded during the four-day period of 10 to 14 July. There were no reports of damage to property in Hong Kong. However, a 12-year-old girl was missing after she slipped into a torrential stream at Sheung Shui on 11 July.

(d) *Tropical storm (15-19 July)*

A tropical depression formed on 15 July about 520 naut mi east of Manila. It started moving west-northwest at 21 kn, but turned westwards on 16 July. It slowed down to 8 kn while crossing the Philippines, and passed close to Manila at 7.00 p.m. on 16 July. On entering the South China Sea it turned north-westwards and accelerated to about 18 kn on 17 July. It intensified into a tropical storm during that night, and slowed down while approaching Hong Kong. In Hong Kong, the stand-by signal, No. 1, was hoisted at 10.30 a.m. on 18 July, when the storm was about 200 naut mi south of Hong Kong. Winds soon freshened from the east, and the strong wind signal, No. 3, was hoisted at 2.10 p.m. on 18 July. During the rest of the day, winds were strong at times off shore and in exposed places. The storm weakened into a tropical depression when it was closest to Hong Kong, about 90 naut mi to the south-west at 2.00 a.m. on 19 July. All signals were lowered at 9.10 a.m. on 19 July, when the depression was 140 naut mi west-southwest of Hong Kong. The storm brought 37.8 mm of rain during the three-day period of 17 to 19 July. Apart from some fallen scaffoldings, damage to property in Hong Kong was minimal.

(e) *Typhoon Joe (18-23 July)*

Joe developed about 160 naut mi west-southwest of Guam. During its whole lifespan, Joe took a west-northwest track and moved at comparatively high speed. The typhoon crossed Luzon early on 21 July. In Hong Kong, the stand-by signal, No. 1, was hoisted at 12.00 noon on 21 July, when Joe was centred 400 naut mi south-east of Hong Kong. In view of the extensive circulation and fast movement of Joe, the strong wind signal, No. 3, was hoisted at 4.15 p.m. A few hours later, strong north-easterly winds set in. The north-east gale or storm signal, No. 8, was hoisted at 4.40 a.m. on 22 July, when Joe was centred 200 naut mi south of Hong Kong. Winds began to turn easterly and gales were soon experienced off shore. The south-east gale or storm signal, No. 8, was hoisted at 10.45 a.m. as winds continued to veer. There were gales in exposed places and off shore throughout the morning and early afternoon, but inside the habour gales only lasted for a brief period. Winds gradually turned south-easterly during the afternoon and then began to subside. The gale signal was replaced by the strong wind signal, No. 3, at 6.05 p.m., when Joe was centred 220 naut mi west-southwest of Hong Kong. Strong south-easterly winds continued for some hours, but all signals were lowered at 1.30 a.m. on 23 July. Joe was closest to Hong Kong around 10.00 a.m. on 22 July, when it was 190 naut mi to the south-southwest. Typhoon Joe claimed two lives in an accident on a construction site in Kwai Chung. One man who was last seen in a sinking junk off Aberdeen Harbour was reported missing. Flying debris or broken glass injured 59 people. Three ocean-going vessels broke away from their anchors and were adrift in the harbour. There were numerous cases of fallen scaffoldings, signboards, traffic signs and trees. However, Joe caused only minor damage to farms and fish ponds in the New Territories. A total of 61.9 mm of rain was brought by Typhoon Joe. The Social Welfare Department handed out a total of 162 cooked meals to nine victims. Damage to public works amounted to $HK 278,500.

(f) *Typhoon Kim (20-28 July)*

Typhoon Kim first developed as a tropical depression about 330 naut mi south-east of Guam. It crossed northern Luzon on 25 July, thereafter weakening considerably. In Hong Kong, the stand-by signal, No. 1, was hoisted at 12.45 a.m. on 26 July, when Kim was about 380 naut mi to the south-east. Typhoon Kim weakened into a severe tropical storm while heading north west towards Dongsha Dao (Pratas Island). As Kim was coming closer to Hong Kong, the strong wind signal, No. 3, was hoisted at 11.10 p.m. Strong northerly winds were first experienced off shore around 5.00 a.m. on 27 July. Winds gradually turned north-westerly in the morning and westerly during the afternoon, and strengthened further. The winds continued to turn and became south-westerly in the evening, with gales for a brief period off shore. Strong south-westerly winds persisted in the morning of 28 July, but as Kim had dissipated overland, all signals were lowered at 7.15 a.m. Kim was closest to Hong Kong around 3.00 p.m. on 27 July, when it was centred about 100 naut mi to the east. Kim brought 136.3 mm of rain to Hong Kong. Violent, squally thunderstorms occurred late in the afternoon of 26 July and the Hammer Hill electric substation was damaged by lightning. This led to an electricity blackout in some districts of Kowloon. A minor landslip occurred on Shouson Hill Road the same evening. Some villages in Tai Po and Sheung Shui were flooded. There were reports of damage to vegetables in the New Territories as a result of squally showers. A landslip also occurred on Lam Kam Road near Kadoorie Farm on 28 July. Typhoon Kim only caused slight damage to property in Hong Kong, and there were no injuries.

(g) *Tropical depression (15-19 August)*

The tropical depression formed 180 naut mi east of Manila. In Hong the stand-by signal, No. 1, was hoisted at 9.10 p.m. on 16 August, when the depression was about 300 naut mi to the south-southeast. The strong wind signal, No. 3, replaced the stand-by signal at 2.35 p.m. on 18 August, when the centre was about 170 naut mi south-southwest of Hong Kong. The tropical

depression was closest to Hong Kong when it was 140 naut mi to the south-west, around 8.00 p.m. on 18 August. Strong winds were experienced in many locations on 18 August. The tropical depression brought 60.7 mm of rain but caused no damage in Hong Kong.

(h) *Typhoon Ruth (12-16 September)*

Ruth formed as a tropical depression on a trough of low pressure about 210 naut mi south of Hong Kong on 12 September. It set out on a westerly course towards Hainan Dao. In Hong Kong, the stand-by signal No. 1, was hoisted at 10.00 p.m. on the same day. Winds strengthened in the afternoon of 13 September and the strong wind signal, No. 3, was hoisted at 5.15 p.m. Easterly winds remained strong on 14 September. As Ruth moved across Hainan Dao, all signals were lowered at 6.30 a.m. on 15 September, and winds moderated in the afternoon. A rainfall of 34.8 mm was recorded in Hong Kong, where no damage was reported.

(i) *Typhoon Percy (13-19 September)*

Percy set out on a west-northwest course after developing at 640 naut mi east-northeast of Manila. The typhoon slowed down after crossing the southern tip of Taiwan. Percy was closest to Hong Kong when centred overland about 190 naut mi to the north-east. In Hong Kong, the stand-by signal, No. 1, was hoisted at 9.15 a.m. on 18 September and the strong wind signal, No. 3, was hoisted at 12.00 noon on the same day. Winds became fresh to strong north-northwesterly during the day, but moderated as Percy weakened overnight. All signals were lowered at 6 a.m. on 19 September, when Percy was about 200 naut mi north-east of Hong Kong. No rainfall was recorded during the approach of Percy, and there were no reports of damage in Hong Kong.

(j) *Tropical Storm Cary (29 October-2 November)*

Cary developed 35 naut mi south-east of Manila on 29 October and moved west-northwest at about 16 kn into the South China Sea. Cary slowed down considerably as it encountered the gale-force north-east monsoon in the northern part of the South China Sea. In Hong Kong, the stand-by signal, No. 1, was hoisted at 4.30 p.m. on 30 October, when Cary was centred about 380 naut mi to the south-southeast. Winds in Hong Kong were moderate easterly and fresh off shore during the night, but turned northerly for several hours the following morning. All signals were lowered at 2.55 p.m. on 31 October, when Cary moved away south-westwards. No rainfall was recorded and no damage was reported in Hong Kong.

F. INDIA

The India Meteorological Department provided information on cyclonic storms during 1980, including a map of the storm tracks (figure 28). The report on the 1980 flood situation in India was provided by the Central Water Commission, together with a statistical statement of flood damage by State (see table 7), based on reports from the various State governments.

1. Cyclonic storms

Cyclonic storm activity in the Indian seas was below normal during 1980, with only three cyclonic storms developing in the Bay of Bengal and none in the Arabian Sea. The storms are briefly described below and their tracks are given in figure 28. No serious damage was reported in association with these storms.

(a) *Cyclonic storm, 16-19 October*

A low-pressure area moved westwards across the Andaman Sea into the south-eastern part of the Bay of Bengal on 15 October and concentrated into a depression on the morning of 16 October, with its centre near 10°N, 88°E. Moving rapidly north-westward, it intensified into a cyclonic storm the following morning, with its centre about 250 km south-east of Masulipatam. It crossed the southern Andhra Pradesh coast between Masulipatam and Kakinada on the morning of 18 October and weakened into a low by the evening of 19 October over central parts of coastal Andhra Pradesh. Under the influence of this system, heavy to very heavy rain occurred in coastal Andhra Pradesh between 18 and 21 October. Notable amounts of heavy rainfall were recorded at Ichchapuram (34 cm), Sompeta (27 cm), Atchanta (Koderu, 23 cm) and Kothapeta (22 cm) on 18 October. Flooding due to heavy rain was reported from some areas in Srikakulam and Visakhapatnam districts. Heavy rain in east and west Godavari districts caused damage to standing paddy, banana and sugar-cane crops. Some damage to roads, buildings and irrigation works was also reported.

(b) *Cyclonic storm, 3-7 December*

A depression formed over the south-west of the Bay of Bengal, about 500 km east-southeast of Negapattinam, on the morning of 3 December. Moving north-westwards, it intensified into a cyclonic storm on the evening of 4 December, about 250 km east-southeast of Madras. It subsequently recurved north-eastwards and dissipated over the west-central part of the Bay by the morning of 8 December. This system caused heavy to very heavy rain in Tamil Nadu on 5 December. No damage was reported in association with this system.

(c) *Cyclonic storm, 12-17 December*

A low-pressure area moved from south in the Andaman Sea to the south-east part of the Bay of Bengal and concentrated into a depression, on 12 December, about 200 km south-west of Port Blair. Moving north-eastwards and becoming deep, it took a clockwise turning over the Andaman and Nicobar Islands area, and moved westwards into the south-east of the Bay on 15 December. Continuing to move westwards rather fast, it intensified into a cyclonic storm

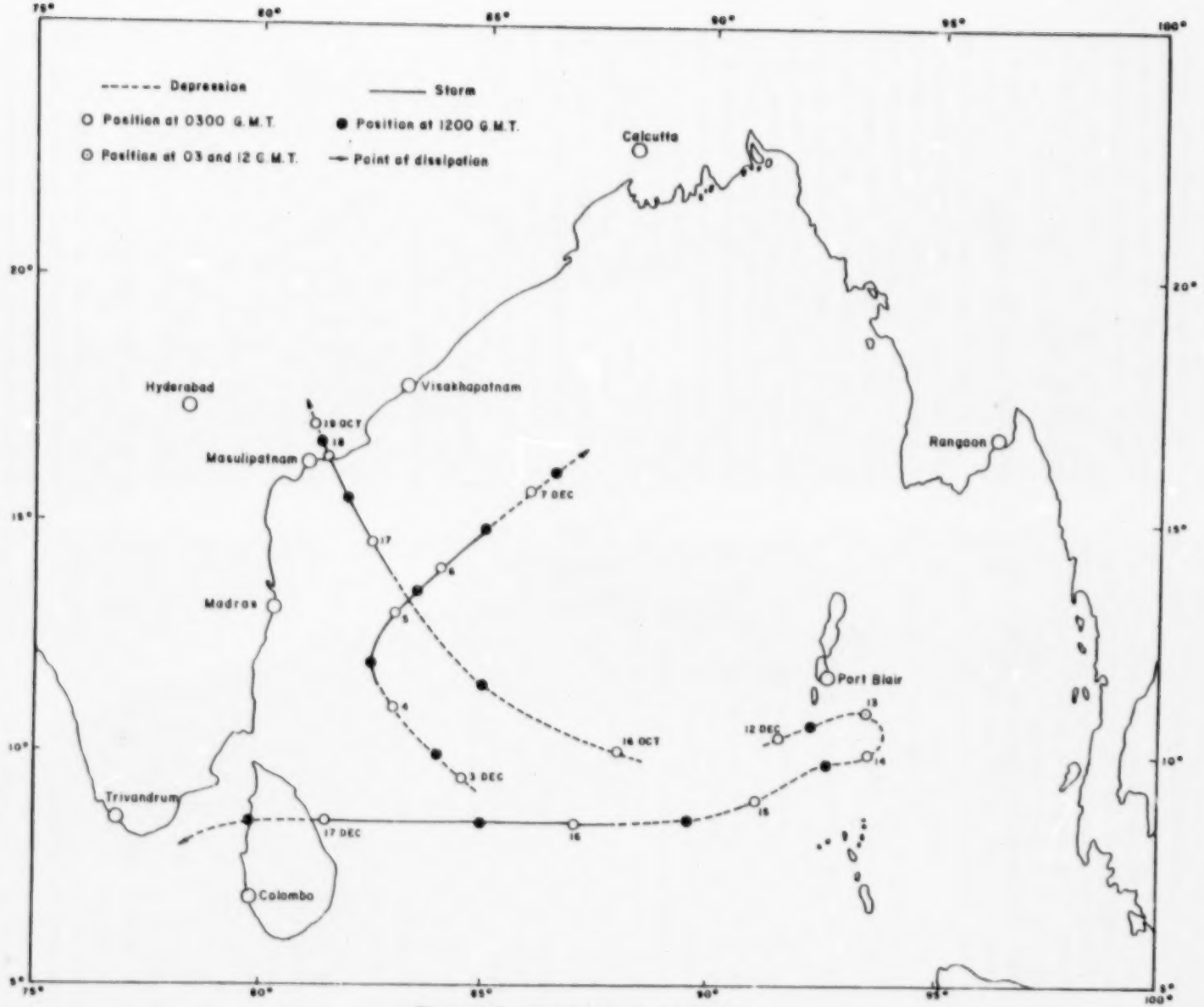


Figure 28. Tracks of storms 1980

Table 7. Flood damage in India during 1980, by State

State	Area affected	Population affected	Human lives lost	Cattle lost	Damage to houses		Damage to crops		Damage to public utilities	Total damage to crops, houses and public utilities (columns 7, 9, 10)
					Units	Value	Area	Value		
1	(1 000 ha) 2	(1 000s) 3	4	(head) 5	6	(1 000 Rs) 7	(1 000 ha) 8	(1 000 Rs) 9	(1 000 Rs) 10	(1 000 Rs) 11
Andhra Pradesh	59	224	88	26 300	34 000	50 000	30	90 000	82 100	222 100
Assam	1 160	3 359	57	9 155	37 457	22 353	287	323 658	51 991	398 002
Bihar	1 920	7 445	67	42	81 015	37 231	996		540 100	577 331
Gujarat	1 322	2 702	45	8 744	24 282	87 598	275	220 195	370 931	678 724
Haryana	156	669	7	14	3 111	7 243	121	204 102	93 100	304 445
Himachal Pradesh	-	7	46	68	405	1 171	-	891	982	3 044
Jammu and Kashmir			1			89	-	50	100	239
Karnataka	20	92	16	4	4 483	1 088	20	10 877	31 411	43 376
Kerala	61	3 600	42	56	36 811	51 274	61	94 267	186 220	331 761
Maharashtra	3	2	29	202	3 576	1 497	3	2 079	46	3 622
Manipur	80	300	7	43	3 688	13 600	47	31 200	17 334	62 134
Meghalaya									6 900	6 900
Orissa	355	2 639	73	8 280	90 000	163 526	355	404 748	603 290	1 171 564
Punjab	45	85	47	113	19 244	7 474	45	43 169	201	50 844
Rajasthan	0	1	1	27	798	454	0	0	2 275	2 729
Tamil Nadu							-	16		16
Tripura			1							
Uttar Pradesh	5 857	30 347	1 309	5 244	1 923 134	1 001 241	3 094	1 901 176	759 500	3 661 917
West Bengal	382	2 620	65	1 095	268 914	262 667	214	333 745	183 735	780 147
Andaman and Nicobar Islands		0.145		14	18	7			56*	63*
Delhi	14		2	0	0	0	1.4	1 200		1 200
Totals	11 421.4	54 092.145	1 903	59 401	2 530 936	1 708 513	5 549.4	3 661 373	2 930 272	8 300 158

Source: Official communication to ESCAP from the Flood Control Directorate, Central Water Commission.

Notes: - Negligible damages.

* Includes huts.

on the morning of 16 December, crossed Sri Lanka on 17 December and weakened into a low over the Gulf of Mannar on 18 December. This system caused exceptionally heavy rain over the Andaman and Nicobar Islands; Port Blair recorded 20 and 22 cm of rain on 12 and 13 December, respectively, and Hut Bay 17 cm on 12 December. No damage was reported.

2. Floods

During the 1980 monsoon, there were spells of heavy rainfall in some parts of the country, which caused floods and drainage congestion resulting in damage to crops, property and loss of life. The total rainfall from 1 June to 30 September was excessive or normal in all parts of the country, except in Nagaland, Manipur, Mizoram and Tripura, the hills of western Uttar Pradesh, western Rajasthan, Rayalaseema, Tamil Nadu and Lakshadweep, where it was deficient. Rainfall was particularly heavy in the State of Gujarat, in the Sourashtra-Kutch region, where unprecedented, widespread rainfall as great as 375 to 500 mm in a single day was experienced, as against an average annual rainfall of 500 to 600 mm. Unprecedented flash floods occurred in the Vamsadhara river in Koraput district, Orissa, and in Srikakulam district, Andhra Pradesh, resulting in colossal losses of crops, property and human life. Heavy rains and floods caused considerable damage in parts of Assam, Bihar, Haryana, Karnataka, Kerala, Punjab, Uttar Pradesh and West Bengal. Also affected were parts of Himachal Pradesh, Jammu and Kashmir, Madhya Pradesh, Maharashtra, Meghalaya, Rajasthan, Sikkim, Tripura, the Andaman and Nicobar Islands, Arunachal Pradesh and Delhi. Flood damage in 1980 is given by State in table 7.

G. IRAN

No damage arising from tropical cyclones, floods or drought was reported during 1980 to the Iranian Meteorological Organization, according to an official communication from the Ministry of Roads and Transportation, Government of Iran.

H. JAPAN

Two typhoons and other heavy rainfall events significantly affected Japan in 1980: Orchid (No. 8013) and Wynne (No. 8019). The Japan Meteorological Agency has contributed the following description of these events, and the statistical table of damages produced by typhoons and heavy rainfall in Japan during 1980 (see table 8).

1. Typhoons

(a) *Typhoon Orchid*

Heading north on 10 September over the sea east of the Okinawa Islands, Typhoon Orchid landed in the south of Kyushu on the morning of 11 September with a central pressure of 962 mb. It crossed the Chugoku district to exit in the Japan Sea on the evening of the same day. Orchid was the only typhoon to hit Japanese soil in 1980. At Aburatsu on the east coast of Kyushu, a wind of 27.3 m/sec from south-southwest was registered. The Nansei Islands, Shikoku and Chugoku areas experienced winds of 15 to 25 m/sec. The largest amount of rainfall produced by Orchid was 651 mm at Nango village in the east of Kyushu, and the 300-mm mark was exceeded at a number of stations in the east of Kyushu, Shikoku and the Kii Peninsula. Other than the damage listed in table 8, a British ship, the "Derbyshire", was reported missing with a crew of 43 in the sea east of Okinawa Island.

(b) *Typhoon Wynne*

Typhoon Wynne indicated a central pressure of 890 mb when moving west of the Marianas on the morning of 9 October; it was the deepest typhoon of the year. Passing west of Okinawa Island northwards on the morning of 12 October, Wynne veered east-northeast and passed near Tanegashima Island on the morning of 14 October, with its intensity weakening. Passing near the Izu Islands, the typhoon then proceeded to the east of the Kanto district. A north-west wind of 30 m/sec was registered at Tanegashima Island. Winds of 10 to 20 m/sec were experienced in the Tokai area and the Izu Islands. Rainfall exceeded 200 mm in the east of Kyushu (with the maximum of 437 mm at Ebino town) and Shikoku. Damage to crops on Tanegashima Island was very extensive.

2. Floods

Summer temperatures were below normal during 1980 owing to the persistent Bai-u front. Many heavy rains came early in July and late in August.

(a) *Heavy rainfall associated with the Bai-u front*

The Bai-u front became very active from late June on, causing rainfall of 100 mm a day or more in some places. The areas affected in the eastern part of Kyushu received 100 to 200 mm of continuous rain a day from 7 to 11 July. Landslides and flooding of rivers disrupted railway services in the Kyushu and Shikoku districts.

(b) *Heavy rains in late August*

A front lying to the south of Japan was stimulated by Typhoon Norris (No. 8012), which tracked from the vicinity of the Nansei Islands to China. This caused heavy rainfall in Japan for a few days from 28 August on. The western part of Japan had 500 660 mm of rainfall during a four-day period from 28 to 31 August. Damage to crops and houses by floods was extensive. Some localities in Hokkaido and Tohoku districts were hit by heavy rains, amounting to 300 to 500 mm.

Table 8. Damage from typhoons and heavy rainfall in Japan during 1980

	Typhoon Orchid (10-11 Sept)	*Typhoon Wynne (13-15 Oct)*	*Heavy rainfall, Bai-u front (7-11 Jul)*	*Heavy rainfall (28-31 Aug)*
Casualties				
Dead or missing	8	4	8	25
Injured	71	23	12	43
Houses				
Destroyed	1	8	8	73
Damaged	101	369	75	243
Inundated	4 023	1 150	3 718	29 524
Cultivated land				
Inundated (ha)	66	75	1 579	4 965
Roads damaged (sites)	65	88	205	526
Bridges washed away		2	2	21
Embankments breached (sites)	5	5	5	22
Landslides (sites)	146	95	564	1 091
Railways disrupted (sites)	7	6	18	55
Communications disrupted (circuits)		226	100	55

Source: Official communication to ESCAP from the Japan Meteorological Agency.

I. MALAYSIA

The following review of floods and droughts in the various States of peninsular Malaysia during 1980 has been compiled by the Drainage and Irrigation Department, Ministry of Agriculture. No major flood or drought was reported to have occurred in Sabah and Sarawak.

1. Perlis

The State of Perlis experienced slight flooding between 16 and 20 October as the result of a rather heavy rainfall in the north and north-east of the catchments of the Perlis River system, brought about by the rain-bearing north-east monsoon. The average total rainfall which fell between 12 and 16 October was about 93 mm, with the heaviest rainfall falling between 12 and 13 October. This heavy rainfall caused the tributaries of the Perlis River system to overflow their banks from their sources down to Kangar town. However, the flooding this time was not extensive and the heavy rainfall did not last for many days. Only 107 people from two villages were evacuated: 20 people from Kampong Lembah Biak and 87 people from Kampung Bakau.

With regard to flood damage, no reports were received as this was considered a mild flood. No reports of drought were received within the period for this State.

2. Kedah

Heavy rainfall recorded downstream of Pedu Dam, Padang Senai and Kuala Nerang (304 mm) between 3 and 17 October caused local flooding in the Kuala Nerang and Kuala Pai areas, in the district of Padang Terap, for about 48 hours. The depth of inundation was 0.5 to 1.0 m. The extent of flooding was 49 ha and 24 ha for Padang Terap and Kuala Pai, respectively. The water level at the flood-assessing point at Kuala Nerang reached a maximum height of 17.98 m, which was 0.91 m above the danger level. The water level at Kuala Pai was 4.9 m, which was 0.98 m above the danger level. A total of 122 people from seven villages of these two areas were evacuated to relief centres.

Heavy rainfall also occurred in the Baling district (195 mm) in the same period. A total of seven villages were affected and the area flooded was about 810 ha. The number of people evacuated to relief centres was 717. The depth of inundation was from 0.5 to 1.0 m and lasted for 48 hours. The Kuala Muda district also experienced flooding during this period. Flooding occurred because of the heavy discharge of the Muda River meeting the high water of the spring tide. The depth of flooding was from 0.5 m to 1.0 m, lasting for 72 hours and spread over an area of 405 ha. A total of 493 people from five villages were evacuated to relief centres.

There was no report of any crop damage during this period as the paddy was harvested just before the occurrence of the floods. There was no report of any drought occurring during the period.

3. Penang

Penang Island experienced an early arrival of the wet season, at the beginning of September. The wet season continued up to December, with heavy precipitation recorded from September to November. Heavy rainfall was recorded during September and October 1980: 469.0 mm and 450.0 mm, respectively. On two occasions, 5 to 6 September and 27 to 28 September, flooding occurred in the low-lying riverine town areas. Several roads were flooded, causing much disruption to traffic flow. Minor floodings in the Pinang River basin, which lasted between two and three days, were of a nuisance nature. No damage was reported in terms of agricultural crops, loss of human lives or epidemic outbreaks.

On the mainland portion of Penang State, i.e., Province Welesley, severe flooding which lasted for two weeks occurred in the low-lying riverine areas of the Muda River basin as a result of the overflow of the Muda. The flooding started on 6 October and ended on 21 October. A total of 14 villages were affected, and 2,054 persons from 439 families were evacuated. There were no casualties or loss of life but there was some damage to crops and livestock. The total damage to crops amounted to $M 18,000.

There was no occurrence of drought during 1980.

4. Perak

There was no major flood in the State of Perak during 1980. However, due to persistent rainfall for two to three weeks during the month of October, a few rivers in Perak overflowed their banks and flooded the riverine areas.

Flooding occurred on the Chenderiang, Kampar and Pari rivers, which are the tributaries of the Kinta River, a major tributary of the Perak River. The Chenderiang River overflowed its banks on the night of 16 October to a depth of 0.3 to 1.22 m, flooding the Chenderiang New Village and the low-lying areas around Chenderiang town. Damages were minimal but great inconvenience was experienced by the residents. The total rainfall on that day was 104.5 mm.

The right embankment of the Kampar River broke for a length of 91 m. About 10 houses were flooded to a depth of 0.6 to 1.52 m, and around 40 people were evacuated.

The Klebang River, which is a tributary of the Pari River, overflowed its banks and flooded 15 houses. People from seven houses were evacuated. The Pari River also overflowed its banks and flooded five villages

along its length to a depth of 1.2 to 1.5 m, causing 25 people to be evacuated from seven houses.

On the Kinta River the water level was very high compared with previous records, as a result of the persistent rainfall that fell for almost two weeks. The highest water level recorded at Tasek was 47.90 m; this was the highest since 13 January 1967, when a level of 47.51 m was recorded. In fact, the flood on 17 October was the worst on record. The depth of inundation varied from 0.6 to 2 m. Five villages were affected and about 150 people were evacuated to reflief centres. Two people were injured when their houses collapsed. Two timber bridges were washed away by the flood, and 215 m of embankment was breached.

The Plus River, which is the tributary of the Perak River, flooded eight villages to a depth of 0.6 to 1.8 m, and 185 people were evacuated. One timber bridge was washed away.

The Perak River was also flooded on 17 October. Nineteen villages along the Perak River were flooded to a depth of 0.6 to 2 m. Another three timber bridges were washed away by the flood. There were no evacuees, although 1,900 residents were affected by the flood.

There was no damage reported as a result of drought.

5. Federal Territory

Flash floods occurred on 25 occasions from January to December 1980, and on seven occasions the floods were due to the river overflowing its banks. A total of 14 villages in the Federal Territory were affected by the frequent flooding. These areas would be flooded after a storm bringing as little as 40 mm rainfall, and the depth of flooding varied from 0.5 to 1.5 m. A total of 900 people were evacuated for two or three days, until the floods subsided.

The damage, in monetary terms, resulting from flooding was estimated at $M 3 million for the whole of 1980. No damage occurred as a result of drought.

The magnitude and frequency of flooding is expected to be very much reduced when the ongoing flood mitigation project in the capital city is completed.

6. Negeri Sembilan

No damage resulting from flood or drought was reported.

7. Malacca

No damage resulting from flood or drought was reported.

8. Johor

No major flood occurred in the State of Johor during 1980, but only some localized flooding. The areas affected by the north-east monsoon were: (a) the upper catchment at the Muar River during the third week of November; (b) the Muphur River, Kota Tinggi, at the end of December. There was no report of the occurrence of drought in the State.

(a) *Muar River basin*

Between 18 and 23 November, there was intermittent heavy rainfall in the upper part of the catchment. As a result, the river bordering the Batu Anam and Buloh Kasap regions overflowed its banks. Several access paths leading to 10 riverine villages were submerged under 0.76 to 1.22 m of water. Road communications were disrupted from 8 to 10 days. Although 1,741 people from these 10 villages were affected, no evacuation was carried out. There was no damage to agricultural holdings, livestock or property. The Muar River monitoring station at Buloh Kasap recorded a peak level of 29.6 m on 29 November. The danger level at this station is 30.0. The rainfall in the catchment over a four-day period from 20 to 23 November was 161 mm.

(b) *Muphur River (Sedili Besar River)*

There was a localized storm in the Muphur River catchment on 28 December. A flash flood resulted and about 100 m of road was flooded; at milestone 8, Jalan Kota Tinggi-Mersing was under 1.1 m of water. The duration of flooding was 36 hours. No damage was caused to crops, livestock and property, but only disruption to road communications. The peak level of the Murphur River was 1.1 m above the danger line. The average rainfall recorded on 28 December in the catchment was 142 m.

9. Selangor

No damage resulting from flood or drought was reported.

10. Pahang

An average of 137 mm of rain fell on the upper catchment of the Jelai River, which is a tributary of the Pahang River, between 14 and 19 October. The rain caused some flash flooding in the upstream villages of this river, but no evacuation was carried out as the flood waters receded quite rapidly. About 30 houses were flooded to a depth of 0.6 to 0.9 m. The damage to crops was very light and there was no damage to property or livestock, or loss of life.

Another storm occurred on the Jelai, Semantan and Lipis rivers, also tributaries of the Pahang River, from 10 to 15 December. The average catchment rainfall was 130 mm. A total of 92 people were evacuated from two villages on the Semantan and Lipis rivers. Damage data were not available at the time of writing.

On the Kuantan River an average rainfall of 200 mm fell between 17 and 21 December. Kuantan town was flooded to a depth of 0.2 to 0.3 m for a period of three to four hours on 18 December as a result of a storm which brought a total of 134 mm of rain and lasted six hours. The cause of flooding was the insufficiency of local drainage. A road bridge at Pasir Kemudi was closed to traffic for one day when the water level was 1.1 m above the bridge. Several low-lying stretches on the Kuala Lumpur/Kuantan road were closed to light traffic for about 10 hours when they were flooded to depth of 0.3 m. No damage was reported.

There was no report on the occurrence of drought in the State during the year.

11. Kelantan

An average of 460 mm of rain fell on the coastal areas of Kelantan from 15 to 20 December. The heaviest daily rainfall was 165 mm, which fell on 16 December and caused the Kemasin and Semerak rivers to overflow their banks. The Kemasin River at Peringat rose from 2.06 to 4.00 mm within 16 hours on 20 December. The level was 0.34 m above the flood level of 3.66 m. The main road between Kota Bahru and Pasir Puteh was flooded to a depth of 0.6 to 1.0 m at milestone 9. Several roads and low riverine areas were also flooded for 36 to 48 hours. The water level of the Semerak River at Pasir Puteh rose from 2.05 to 2.85 m within 28 hours on 19 December. The maximum water level was 0.41 m above the flood level of 2.44 m. Pasir Puteh town was flooded to a depth of 0.1 to 0.2 m for 48 hours. The Kota Bahru/Pasir Puteh/Semerak main road at milestones 21, 23, 27 and 29½ was under 0.1 to 0.3 m of water for a period of 10 to 24 hours. About seven villages were affected by this flood. A total of 30 families in the Pasir Puteh area were evacuated for several days. Four ha of paddy in the Pasir Puteh area were destroyed, and 20 ha more in the Bachok area were also destroyed.

The Golok River at Rantau Panjang rose from 8.21 to a maximum of 9.15 m on 21 December. The floods were of moderate nature. No evacuation was carried out; only one village was flooded to a depth of 1 m. Three children were drowned in the Golok River area. The total damage in monetary terms was not assessed.

There is no report on the occurrence of drought in the State during the year.

12. Trengganu

Only minor flooding and some localized floods occurred in the five districts of the State of Trengganu for the year. The losses in monetary terms were as follows: agricultural facilities, $M 150,137; livestock, $M 400; paddy, $M 6,300; houses, $M 3,000; other crops, $M 71,048. The total flood damage was $M 230,885.

The losses resulting from drought amounted to $M 282,125 for paddy and to $M 32,799 for other crops.

The total damage resulting from flood and drought during 1980 amounted to $M 545,800.

J. NEW ZEALAND

Significant meteorological events in New Zealand in 1980 were reported by the New Zealand Meteorological Service, which also compiled the following brief report on named tropical cyclones affecting land areas in the south-west Pacific.

Most of New Zealand experienced above-normal rainfall during 1980, with some western North Island and southern South Island areas recording 30 to 40 per cent more rain than usual.

1. Flooding in Southland/Otago (January)

For some days preceding 16 January, north-westerly winds over a very long stretch from the north Tasman Sea drew down a large mass of warm, moist air to the New Zealand region. The high moisture content of this air, combined with the very deep low which subsequently formed off the Otago coast, were the main factors leading to the high rainfall and flooding in parts of Southland. By 9 a.m. on 16 January the axis of a trough of low pressure lay about 150 km west of Fiordland, with a strong, cold, southerly airstream to the rear covering the west Tasman Sea. At this time, winds were light over much of South Island, with many stations reporting overcast skies but no rain.

In the next six hours, pressures over South Island dropped about 10 mb and rain began to fall inland in Southland. As the lowest pressures moved to the east of South Island, the cold southerly airstream in the Tasman Sea advanced over Fiordland. By 6 p.m. on 16 January, Puysegur Point reported a 45-kn southerly wind and the pressure at Oamaru had dropped to 967 mb. By 6 a.m. on 17 January, dramatic deepening had taken place, with a low centre of 954 mb just off the Otago coast. The lowest pressure recorded at a land station was 961 mb at Taiaroa Head. This compares with the New Zealand record low pressure of 954 mb, which occurred in 1939 (coincidentally, on 16 January) and also at Taiaroa Head. South to south-west winds spread over Southland and Otago, reaching up to 60 kn in coastal places, and rain continued to fall over a wide area south of Christchurch.

The 24-hour rainfalls in the Lower Clutha and in the Mataura river catchments were quite comparable to those of the October 1978 flood. In general, over 100 mm fell in the 24 hours from 2 p.m. on 16 January in the upper Mataura and Oreti catchments, and more than 120 mm in the Pomahaka Waikaia and Waikaka catchments, where the heaviest rain occurred during the night of 16 to 17 January.

2. Taieri Plains (Otago) floods (June)

A trough of low pressure lay over the Tasman Sea on 2 June, and early on 3 June a depression formed in the north Tasman Sea within the trough. By 4 June the depression was deepening as it moved towards South Island. During the early morning of 4 June, heavy rain began to fall in southern Canterbury, Otago and parts of Southland, and this resulted in major flooding of the Taieri Plain between Mosgiel and Henley, and also near the mouth of the Clutha River. At Outram, the Taieri River broached its banks and approximately 2,000 people were evacuated from their homes on the Taieri Plains. At one stage during the peak of the flooding, 700 dairy cows were herded onto the flood-free main highway at Henley. Flood waters cut most of the State highways and minor roads in the area, and Momona Airport was closed when the runway and buildings became flooded. At Musselburg (Dunedin) 119 mm of rain were recorded between 9 a.m. on 4 June and 9 a.m. the following day, this being the highest one-day all in any month since April 1923 (229 mm). At Islay Downs (Glendale) and Ross Creek, more than 120 mm were measured during the same period.

3. Gisborne/Hawkes Bay floods (December)

A slow-moving depression which formed off the west coast of South Island on 21 December lay near North Cape on 23 December, and persisted until 29 December. Moist easterlies on the southern side of the depression flowed over North Island, and heavy rain fell in the Gisborne and Hawkes Bay areas between 23 and 28 December. In the Gisborne region, heavy rain in the ranges from 23 to 26 December caused the Waipaoa River to rise on 27 December about 9 m above the normal level, threatening to isolate the township of Te Karaka. A 48-hour rainfall from 9 a.m. on 25 December to 9 a.m. on 27 December took place at Otoko (257 mm), Te Karaka (109 mm), Gisborne (57 mm), Makaretu North (near the headwaters of the Waipaoa River; 148 mm), Kairoa (189 mm) and East Cape (111 mm).

In Hawkes Bay, the Heretaunga Plains were flooded on 28 December when the Ngaruroro River burst its banks at Tywford. An estimated 800 to 1,000 ha of orchard and market-garden land were inundated with flood waters, which caused the destruction of crops. At the height of the flood there was an estimated discharge of 2,500 m^3/sec of water in the river at the Fernhill gauging station, which corresponds to a return period of 35 years.

During the seven days from 22 to 28 December, the following rainfall totals were recorded: Brentford, 449 mm; Smedley, 364 mm; Te Hau, 380 mm; Blackburn, 288 mm; and Guvavas, 277 mm. These rainfalls were among the highest ever recorded at any Hawkes Bay station for a seven-day period.

K. PACIFIC SOUTH-WEST (GENERAL)

Table 9. Tropical cyclones in Pacific south-west areas, 1980

Name	*Date*	*Intensity*	*Area affected*	*Damage*
SIMON	March	Gale (hurricane earlier)	North Island of New Zealand	Minor
SINA	March	Storm (hurricane earlier)	North Island of New Zealand	Minor
TIA[a]	March	Storm	North-eastern Fiji	Some damage from winds and storm surge
VAL	March	Storm	Futuna group	Not known
WALLY[b]	April	Gale (marginal)	Fiji	Severe flooding and devastation by landslides in south-east Viti Levu, from heavy rainfalls (of the order of 1500 mm in four days, in some places)

Source: Official communication to ESCAP from the New Zealand Meteorological Service, Ministry of Transport, Government of New Zealand.

Notes: *a* See Fiji country report, in part III of this *Journal*, for a description of Tia in the vicinity of Fiji.

b Wally was a rain depression and did not become a true tropical cyclone. For a description of Wally in the vicinity of Fiji, see the Fiji country report in part III of this *Journal*.

L. PAKISTAN

The Pakistan Meteorological Department provided ESCAP with the following report on flood events during the 1980 monsoon season (June to September). No tropical storms affected Pakistan during the year.

The outstanding feature of the 1980 monsoon season was the devastating spells of heavy rain over the city of Lahore and its adjoining eastern and southern districts, which were declared calamity-struck areas. Lahore Airport received an all-time record rainfall for the season. Another significant feature was the early onset and early withdrawal of the monsoon from the country. The first monsoon incursion into the country took place during the second week of June, and it started to show signs of weakening during the third week of August, finally withdrawing during the first week of September.

A total of 10 monsoon lows or depressions developed in the Bay of Bengal and moved inland across India. However, only six of these affected Pakistan (see figure 29) and caused moderate to heavy and a few extremely heavy falls in the catchment areas of the rivers of northern Punjab. Of the 10 monsoon lows or depressions, five recurved towards western Uttar Pradesh and the Indian Punjab hills.

1. Seasonal rainfall and floods

(a) *Seasonal rainfall*

In the seasonal isohyetal map (figure 30), there are two cells of maximum rainfall of 85 to 100 cm. One of them lies over part of the Indus catchment (onward Basham Qila) and at Jhelum (onward Murree), and the other over Lahore Division. Two other cells of 37 to 50 cm of rainfall lie along the upper and middle catchment of the rivers Ravi, Chenab and Kurram, and parts of Rawalpindi and Sargodha Divisions. The rainfall decreases to 13 cm or less over south-west Punjab, D.I. Khan Division of the North-West Frontier Province (NWFP), Gilgit Agency and the upper valley of the River Indus.

The isopercental map (figure 31), or departure from seasonal normal, shows that major parts of Lahore and Sargodha Divisions had rains 100 to 180 per cent above normal. The catchment area of the River Indus, the Peshawar and Malakand Divisions of NWFP and Gilgit Agency received 50 per cent more rainfall than normal. In the greater part of Rawalpindi and Multan Divisions, rainfall was practically normal, whereas in the south-western Punjab, parts of Rawalpindi Division, Kashmir and the lower catchment areas of the rivers Ravi, Chenab and Indus, rainfall was from 20 to 50 per cent below normal.

(b) *Floods*

High flood peaks were recorded at Marala on the Chenab River on 24 June and 15 July, and at Mangla on the Jhelum River on 24 June. A very high flood peak was recorded at Jassar on the Ravi River on 15 July. Otherwise, generally low and a few medium floods occurred during the months of July and August (see table 10) in the rivers of the Indus basin, except for the Sutlej River.

2. Meteorological aspects of the floods

(a) *June*

The first monsoon depression of the season developed in the Bay of Bengal on 16 June off the coast of Orissa and moved inland on 17 June. It moved in a northerly direction until 18 June, and thereafter turned towards the north-west. It was centred over east Sind and adjoining areas on 23 June and rapidly weakened off the Sind coast by 25 June. Simultaneously, a westerly low-pressure wave moved across the north of Pakistan on 23 and 24 June. Under the combined influence of these two factors, local to fairly widespread rain with a few heavy to very heavy falls occurred over the northern areas of Pakistan and Kashmir, and local, light to moderate falls in Sind. Noteworthy rainfalls were reported from Kotli (162 mm) and Pallandri (89 mm) on 24 June; Kakul (98 mm) and Murree (52 mm) on 25 June; and Lahore (76 mm) and Bahawalpur (33 mm) on 26 June. As a result of the very heavy falls in upper catchments, high flood peaks were recorded at Marala over Chenab and at Mangla over Jhelum on 24 June. The River Ravi also recorded a rise at Jassar, but the peak remained below low flood level.

(b) *July*

The second depression that affected Pakistan crossed the coast near Balasore (Orissa) on 27 June. After moving initially north-westward and then westwards, it lay close to Nagarparkar south-west of Sind on 4 July and rapidly weakened by 5 July. In its wake, the axis of the monsoon trough shifted northwards, and caused convergence into the northern parts of the country where fairly widespread rain with locally heavy falls were recorded. The principal rainfalls were those reported from Sargodha (87 mm), Mianwali (65 mm) and Islamabad (51 mm) on 6 July. As a consequence of these heavy falls, the Chenab and Jhelum rivers rose to a low flood stage.

An easterly low, moving along the axis of the monsoon trough, reached Bikaner (Rajasthan) on the morning of 10 July. Thereafter it recurved north-northeast and, moving across east Punjab and adjoining areas of Pakistan, it reached Himachal Pradesh on 14 July and subsequently filled up. It caused heavy to very heavy falls over the Indian Punjab and adjoining parts of Pakistan between 10 and 13 July. Noteworthy amounts in Pakistan were reported from Multan (99 mm) on 10 July; Lahore (69 mm), Sialkot (49 mm) and Murree (45 mm) on 13 July; and Chak Amru (110 mm)

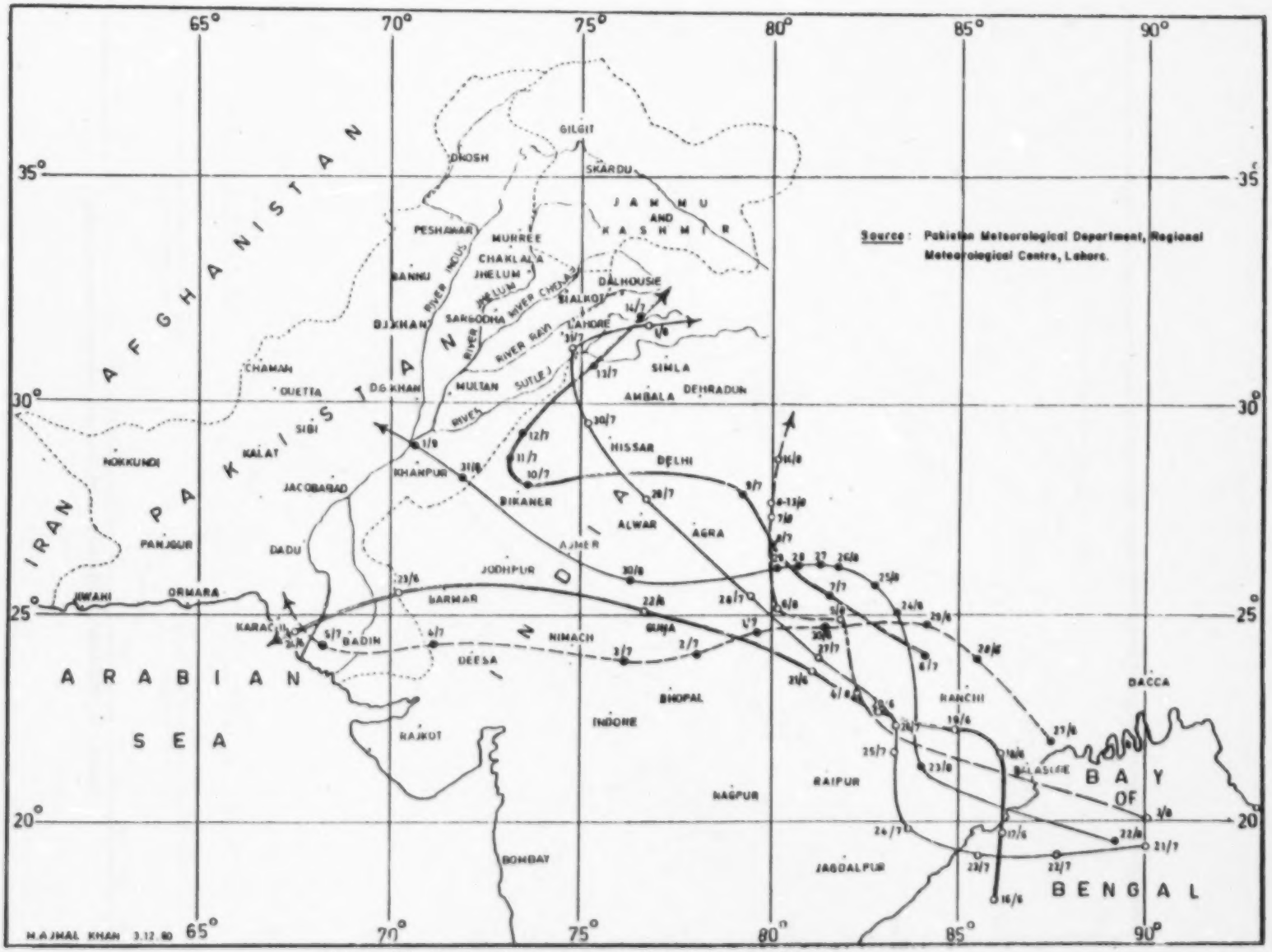


Figure 29. Tracks of monsoon depressions during the 1980 monsoon season

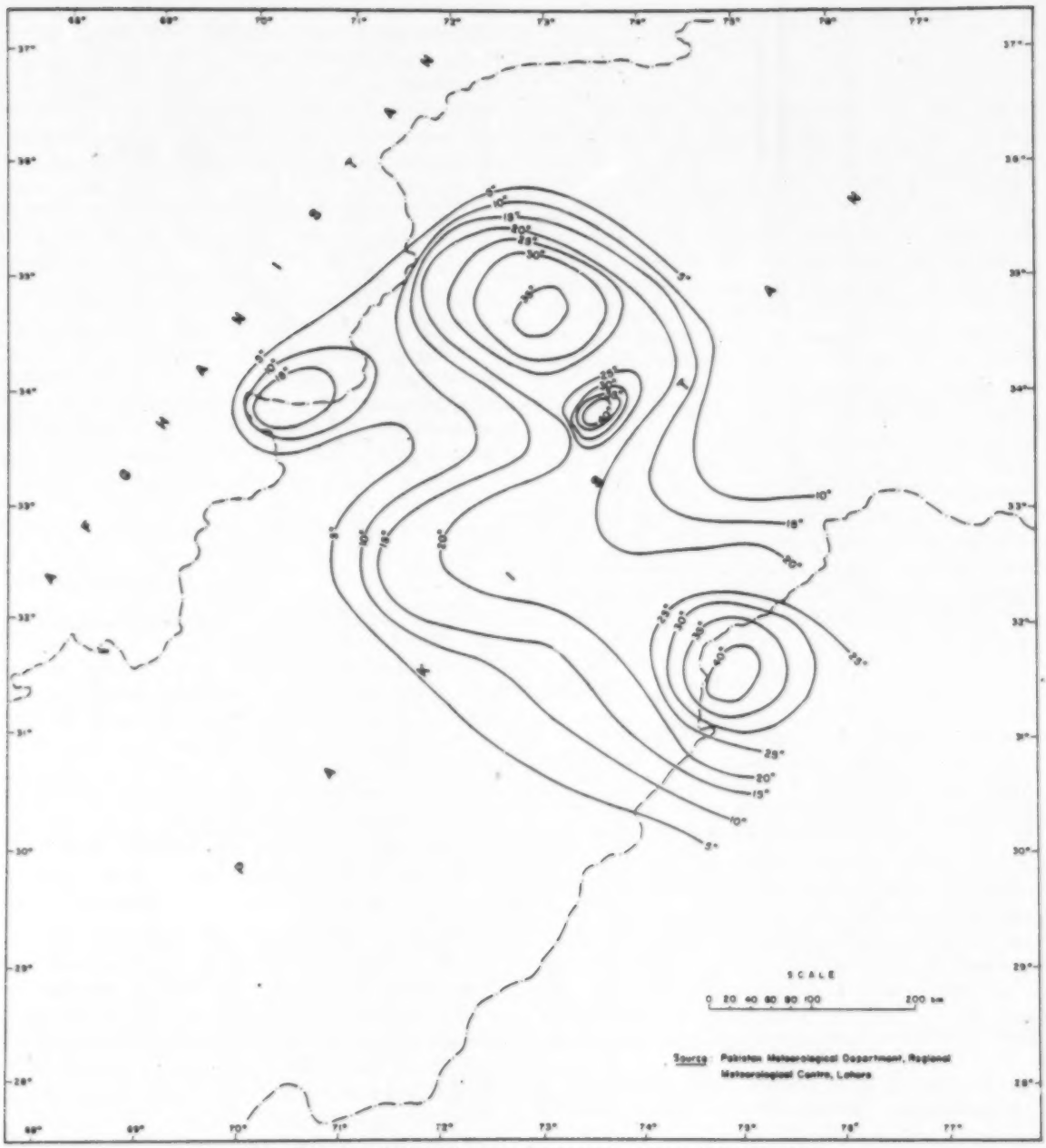


Figure 30. Seasonal isohyetal map of monsoon season, Pakistan, 1980

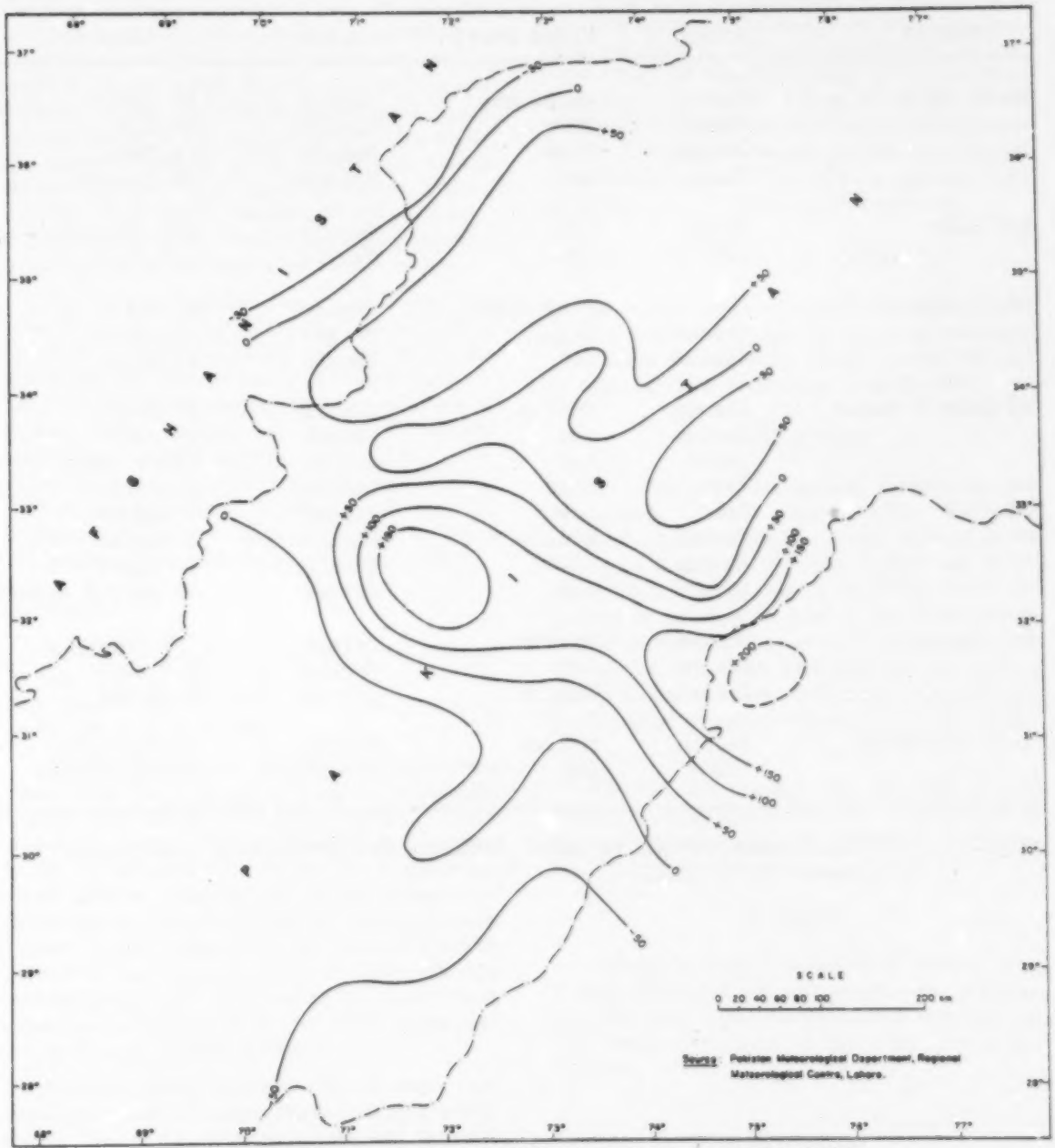


Figure 31. Isopercental of normal rainfall, June - September 1980, in Pakistan

Table 10. Flood levels in Pakistan, June-September 1980

Period	*River*	*Flood level*	*Place*	*Date*
24-27 June	Ravi	Below low	Jassar	25 June
	Chenab	High	Marala	24 June
	Jhelum	High	Mangla	24 June
	Indus	Low	Attock	28-30 June
4-7 July	Chenab	Low	Marala	5-6 July
	Jhelum	Low	Mangla	5-6 July
10-17 July	Ravi	Very high	Jassar	15 July
	Chenab	High	Marala	15 July
	Jhelum	Low	Mangla	11 July
23 July-3 August	Chenab	Medium	Marala	27 July
	Jhelum	Low	Mangla	26 July
	Indus	Low	Attock	23-27 July
	Ravi	High	Balloki	2 August
	Ravi	Low	Jassar	3 August
	Chenab	Medium	Marala	3 August
	Jhelum	Low	Mangla	3 August
	Indus	Low	Attock	30 July-4 August
6-9 August	Chenab	Medium	Marala	7-9 August
	Jhelum	Low	Mangla	9 August
	Indus	Medium	Attock	8 August
6-10 September	Jhelum	Medium	Mangla	10 September
	Indus	Low	Attock	2-7 September

Source: Official communication to ESCAP from the Meteorological Department, Government of Pakistan.

and Jassar (100 mm) on 14 July. As a result of these heavy falls, particularly over the contiguous Indian areas, very high flood peaks were recorded over Ravi, and high flood peaks over Chenab on 15 July. After a few days, the monsoon again became active from 23 July. This occurred under the influence of a monsoon depression which formed in the north of the Bay of Bengal on 21 July, crossed Orissa coast on 23 July and, in alignment with the monsoon trough extending from Central Punjab to Orissa, caused deep penetration of moisture into the region. Sporadic heavy falls of rain occurred over the upper NWFP and the north Punjab between 24 and 27 July. Kakul received 97 mm of rain and Murree 71 mm on 24 July; Murree and Jhelum 50 mm each on 25 July; Lahore 76 mm on 26 July; and Mianwali 90 mm and Sargodha 64 mm on 27 July. Consequently the River Chenab had a medium flood on 27 July and the River Jhelum a low flood on 26 July.

The monsoon depression, moving north-westwards from Orissa, reached the south-east of Lahore Division on 31 July, thereafter recurved north-east and finally moved into the hills of Himachal Pradesh, where it filled up. It caused devastating rain over Lahore and its vicinity during the last two days of the month. Outstanding rainfall amounts were reported from Hudiara (225 mm) on 30 July, and from Lahore Airport (333 mm) and Hudiara (140 mm) on 31 July. The Hudiara and Nikki Dek Nullahas were inundated, causing high floods at Balloki over the River Ravi on 2 August.

(c) *August*

In the aftermath of the heavy rains towards the end of July, medium flood levels were recorded on the River Chenab, and low flood levels in the other rivers of the Indus basin on 3 August.

The first depression of the month developed in the north of the Bay of Bengal on 3 August, and initially moved north-west until 6 August. Thereafter it took a northerly course, reached the foothills of the Himalayas in the north-west of Uttar Pradesh by 8 August and slowly filled up. Under its influence the monsoon was active over the northern Punjab and adjoining Kashmir between 6 and 9 August. The chief amounts of rainfall reported during the period were from Jhelum (76 mm) and Sialkot (35 mm) on 9 August. The River Chenab experienced a medium flood on 7 and 9 August, and the Jhelum a low flood on 9 August.

Monsoon activity slackened after 10 August and continued so until 23 August. Thereafter it again revived slightly under the influence of the last monsoon depression of the season, which formed over the Bay of Bengal on 22 August and moved in a north-northwesterly direction until 26 August. Subsequently it took a westerly course until it finally merged with the seasonal low over Baluchistan on 1 September. Significant amounts of rainfall were reported from Sialkot (49 mm), Murree (44 mm) and Islamabad (28 mm) on 24 August; Islamabad (44 mm) on 26 August; Sargodha (38 mm) on 30 August; and Kakul (54 mm) on 31 August. The rains did not cause any significant rise in the rivers, and flows remained below the flood level.

(d) *September*

The monsoon incursion withdrew completely from the region during the first week of the month. However, under the influence of an accentuated seasonal low, coupled with the occasional passage of westerly waves across the northern parts of Kashmir, sporadic rainfall activity occurred in the northern parts until 10 September. The River Jhelum attained a medium flood level on 10 September. After 12 September an almost-dry spell prevailed, and rivers continued to flow rather low.

M. PAPUA NEW GUINEA

The National Weather Service of Papua New Guinea reported that no major loss of life or damage was caused by floods or drought in the country during 1980, and no tropical cyclones developed in the general area.

N. PHILIPPINES

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) compiled tabular reports on damage incurred in the Philippines as a result of tropical cyclones and floods during 1980. Damage inflicted by named storms and cyclones is presented in table 11 and flood damage incurred in several of the country's regions is reported in table 12. PAGASA estimated that total cyclone damage amounted to over 1,400 million pesos and total flood damage amounted to more than 1,300 million pesos.

PAGASA also reported that no severe drought affected the Philippines during 1980. Some parts of the country experienced deficient rainfall, but no damage resulted from that deficiency.

O. SAMOA

Damage in Samoa during 1980 resulting from tropical cyclones, floods and droughts was negligible, according to an official communication from the Apia Observatory, Department of Agriculture, Government of Samoa.

P. SINGAPORE

No tropical cyclone affected Singapore during 1980, and no drought was experienced.

The Meteorological Service, Singapore, reported that local floods of short duration were experienced several times during the year, but no lives were lost and damage to property was not serious.

Table 11. Tropical cyclone damage in the Philippines, 1980

Event	Areas affected Province/Place	Casualties	Homes destroyed	Damage (1 000 pesos)	
Tropical Storm Biring 20-24, 27 March	Eastern Samar	1 death 100 families homeless		crops roads, bridges	500 1 000
	Western Samar	3 deaths 563 families homeless	18 totally 75 partially	crops private, public properties houses	8 1 500 50
Typhoon Ditang 20-21 May	Isabela: Palanan	1 585 families affected	total reported for Ditang: 165 totally 528 partially	infrastructure public buildings crops	100 20 100
	Maconacon	950 families affected		crops	30
	Dinapigue			crops	50
	Cagayan: Sta. Teresita			public, private properties crops livestock	30 20 9
	Benguet: Baguio City			house.	11.5
	La Trinidad			crops	1 500
	Sablan			crops	15
	Kabayan			crops	50
	Atok			crops	20
	Mountain Province			roads, bridges crops	95 125
Tropical Storm Gloring 22-26 May	Tarlac: Anao	negative report		crops public property	34 12
	Nueva Ecija	negative report		crops	862
Typhoon Lusing 7-11 July	Batanes	negative report		crops	6 500
Typhoon Mitang 18-22 July Typhoon Osang 22-27 July		36 deaths 4 missing 55 injured	10 451 totally 18 279 partially	crops, roads, bridges	101 708
Typhoon Undang 14-18 September	Luzon and Mindanao	---------- negative report ----------			
Typhoon Welfring 10-12 October	Batanes: Basco Cagayan: Aparri	---------- negative report ----------			
Tropical Storm Yoning 28-30 October	Bulusan		1 totally	crops public, private property houses	1 505 150 5
Typhoon Aring 1-7 November		103 deaths 25 missing	5 431 totally 29 654 partially	crops public property private property roads, bridges public works	871 626 88 779 145 802 179 310 59 184
Tropical Depression Baslang 11-13 November		negative report		roads crops government property public buildings	70 39 19 71

Source: Official communication to ESCAP from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Ministry of National Defense, Government of the Philippines.

Table 11. Flood damage in the Philippines, 1980

Areas affected	Population affected families/persons	Population assisted families/persons	Casualties dead/missing	Houses destroyed totally/partially	Damage by category of property (units: 1 000 pesos)					
					Agriculture*	Public property	Private property	Roads, bridges	Public works	Total
Region II										
Nueva Vizcaya	14 112/84 548	190/1 032	27/12	1 033/14 112	16 000	4 550	6 550	42 700	400	70 200
Isabela	37 851/227 107	1 460/8 014	16/11	59/-	60 808	4 047	14 671	4 367	-	83 893
Kalinga Apayo	1 070/6 420	-/-	-/-	-/-	1 495	980	1 375	1 315	-	5 165
Cagayan	54 000/324 000	19 340/35 840	26/-	352/45	243 849	138	100 000	70	8 735	352 792
Quirino	1 535/9 210	200/1 089	4/-	1 894/16 857	37 324	1 439	263	24 570	-	63 596
Ifugao	750/4 083	-/-	-/-	-/-	1 710	2 253	3 740	9 740	5 630	23 073
Batanes	-/-	-/-	-/-	-/-	350	250	-	-	-	600
Region III										
Aurora	5 952/30 778	4 958/20 875	10/2	1 864/3 934	16 264	5 900	9 707	4 507	2 745	39 123
Bataan	358/2 148	282/1 378	-/-	3/318	8 062	500	92	2 284	4 785	15 723
Bulacan	29 227/141 932	14 867/74 392	2/-	-/-	24 673	-	-	2 826	6 317	33 816
Nueva Ecija	49 815/255 416	21 956/131 023	12/-	79/601	300 668	2 023	4 275	55 759	7 363	370 088
Pampanga	25 349/141 301	14 737/88 479	6/-	37/40	49 179	65	2 035	2 450	9 734	63 463
Tarlac	6 276/33 120	3 655/19 134	-/-	19/150	58 776	815	908	10 757	2 942	74 198
Zambales	400/2 202	195/1 138	-/-	21/88	400	-	-	1 489	5 863	7 752
Region V										
Camarines Sur	12 778/93 226	55/292	-/-	525/1 917	3 218	1 000	-	1 200	1 037	6 455
Sorsogon	186/1 116	-/-	-/-	33/59	2 680	385	-	386	395	3 846
Camarines Norte	5 404/27 020	2 785/14 544	-/-	831/4 573	15 028	179	234	320	100	15 861
Catanduanes	583/3 498	109/588	-/-	46/118	2 875	381	479	174	-	3 909
Albay	37/225	165/954	-/-	37/67	6 988	1 771	20	-	3 000	11 779
Masbate	131/786	166/841	-/-	27/48	303	50	-	103	99	555
Davao del Norte (15 municipalities)	6 416/34 292									8 935

Source: Official communication to ESCAP from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Ministry of National Defense, Government of the Philippines.

Notes: * "Agriculture" denotes crops, livestock and fishponds.

The official exchange rate for the 1980 statistics is 7.85 pesos per $US 1.

Q. SOLOMON ISLANDS

No significant damage was caused by cyclones or flood during 1980 in the Solomon Islands, according to an official communication from the Ministry of Works and Public Utilities, Government of the Solomon Islands.

R. THAILAND

The most significant weather event in Thailand during 1980 was the occurrence of floods during the rainy season, the Meteorological Department reported. Damage caused by floods throughout the year was valued in excess of B 1,545 million and 61 lives were lost. Table 13 gives statistics of the major components of flood damage in the five principal geographic regions of Thailand.

1. General monsoon summary

During the period of the 1979/80 north-east monsoon, locally considered as the winter season (November to February), occasional surges of a high-pressure area from China extended to cover upper Thailand and brought cold weather in general during the second period of the north-east monsoon (January-February). Very cold weather occurred only in the northern portion of northern Thailand. An extreme minimum temperature of 6.0°C was recorded on 29 January at Tha Wang Pha of Nan province. The summer season extended from March to the first half of May, with a heated low-pressure cell prevailing over upper Thailand almost throughout this period. This condition caused temperature increases and sultry weather in general. Occasional outbreaks of the continental high-pressure area from China spread down to upper Thailand, so that the daily mean air temperature was not so high as usual. Lampang province in northern Thailand reported the highest temperature (43.2°C) on 1 May; this was a new record for the 30 years since 1951. The rainy season, or south-west monsoon, began in the middle of May 1980. During this season, widespread rain showers with widely scattered, heavy to very heavy falls were experienced over upper Thailand, as a result of the monsoon trough and tropical depression in upper Thailand.

Tropical depressions

In 1980, three tropical depressions affected Thailand. On 13 May, a tropical depression developed over the Bay of Bengal at 11.5°N, 89.5°E and moved westward. On 17 May it recurved eastward, passing through the Andaman Sea toward the Bay of Mataban. On 20 May, at 0700 hours, the depression intensified into a tropical cyclone with its centre at about 13.7°N and 98.0°E and subsequently weakened into a depression in the afternoon. It then moved eastward over Burma, passed through Thailand on 21 May in the vicinity of Ratchaburi province, weakened into a low-pressure cell and finally dissipated on 22 May. During this period the low-pressure trough lay across the central and eastern parts of Thailand. Consequently, widespread rain showers with isolated heavy to very heavy falls were experienced in upper Thailand. The maximum 24-hour rainfall was 146.0 mm, observed at Udon Thani on 21 May.

On 4 September, a low-pressure cell intensified into a tropical depression centred about 300 km east of Nha Trang, Viet Nam (12.8°N, 111.7°E) and moving westward. It passed over the Vietnamese coast on 6 September, heading for north-eastern Thailand. At 1300 hours on the same day, its centre was in the vicinity of Nakhon Phanom province, and it continued westward, passing through Udon Thani, Loei, Uttaradit and Lampang provinces. At 1900 hours on 7 September it was centred between Chiang Mai and Lampang provinces, moving west-northwest. Finally it weakened into a low-pressure cell on 8 September and dissipated on its course to Burma. Widespread rain showers with scattered heavy to very heavy falls were experienced in the northern and north-eastern parts of Thailand during 5 and 6 September. The maximum 24-hour rainfall was 156.2 mm, which was observed at Nam Pat district of Uttaradit province in the northern part of Thailand on 5 September.

A tropical depression in the South China Sea intensified into Tropical Storm Ruth on 15 September, at about 19.5°N, 110°E, and moved west-northwest. On 16 September it changed its direction to west-southwest, passed over the Vietnamese coast and weakened into a tropical depression while passing over Lao People's Democratic Republic. It entered northern Thailand in the vicinity of Uttaradit province on 17 September, and centred at about 17.6°N, 100.3°E at 0700 hours. It continued moving west-southwest, weakening into a low-pressure cell at Sukhothai province on the same day and finally dissipating after passing over Burma. Widespread rain showers with isolated heavy to very heavy falls were experienced in the northern and north-eastern parts of Thailand from 15 to 20 September. The heaviest 24-hour rainfall was 146.8 mm, observed at Sahatsakhan district of Kalasin province in the north-eastern part of Thailand on 15 September.

2. Floods

Severe flooding was experienced over vast areas of northern, north-eastern and central Thailand, including Bangkok Metropolis and surrounding areas, from early September to mid-November 1980; this was apparently caused by excessive rainfall brought about by two depressions which invaded Thailand on 6 and 7 September and 17 September, and a persistent, active monsoonal trough in upper Thailand during September and early October. Flooding in 47 provinces of upper Thailand and in one of southern Thailand affected 203,386 families, or 831,368 persons, and 2,394 houses

Table 13. Estimates of damage caused by floods in Thailand during 1980

Region	Provinces	Districts	Population affected		Population evacuated		Casualties		Houses destroyed		Farmlands flooded		Public utilities damaged						
			Families	Persons	Families	Persons	Dead	Injured	Units	Estimated damage (baht)	Area (ha)	Estimated damage (baht)	Highways (km)	Bridges	Weirs	Official premises	Schools	Temples	Estimated damage (baht)
North	17	124	12 998	52 426	9	30	7	-	1 441	422 285	332 649	34 488 324	1 003	274	291	19	48	34	30 075 127
North-east	14	147	130 957	586 643	11 672	68 666	20	6	149	151 000	373 178	191 544 800	1 177	236	357	25	20	3	102 036 892
Central Plains	12	66	59 341	192 115	208	1 308	34	1	796	796 174	220 604	753 912 875	1 211	74	141	35	179	96	45 489 806
East	4	15	87	160	20	102	-	-	4	-	1 431	11 927	129	19	4	-	-	-	11 853 240
South	1	1	3	24	-	-	-	-	4	25 500	-	-	4	7	-	-	-	-	753 500
Total	48	353	203 386	831 368	11 909	70 106	61	7	2 394	1 394 959	927 862	979 957 926	3 524	610	793	79	247	133	190 208 565

Source: Civil Defense Division, Department of Local Administration, Ministry of the Interior, Government of Thailand.

Notes: Currency: baht (B 20.595 = $US 1.-)
Areal units: hectares (ha)

were destroyed. A total of 61 persons were reported dead and seven others were injured during the flood events. It was estimated that about 927,862 ha of farmland were damaged, from which 11,909 families or 70,106 persons were evacuated to safer places. The total damage caused by the 1980 flood in upper Thailand, excluding the Bangkok Metropolitan area, was estimated at around B 1,545,754,797. Estimates of the damage caused by the 1980 floods are given in table 13.

The flooding in the lower Chao Phraya River delta areas, particularly in Bangkok Metropolis, was prolonged and occurred from early October to mid-November. The damage incurred by the 1980 flood in Bangkok Metropolis itself has been roughly estimated at many millions of baht. Thousands of urban residents were affected, and many outlying orchards were inundated. The 1980 flood is regarded as one of the most disastrous such weather events ever recorded in Thailand.

3. Droughts

In 1980 Thailand experienced below-normal rainfall in general during the first half of the year, but no significant droughts were reported. Although short drought periods were observed in certain areas of upper Thailand, no significant damage was reported in terms of economic loss or adverse effects on people.

S. TRUST TERRITORY OF THE PACIFIC ISLANDS

The Office of Planning and Statistics issued the following brief report on damages resulting from cyclones during 1980.

Although several tropical storms and typhoons threatened the Trust Territory of the Pacific Islands, only one significant storm (Typhoon Dinah) hit the Northern Mariana Islands of Saipan and Tinian, early in the morning of 23 November, with maximum sustained winds of 100 kn and gusts up to 130 kn. Damage sustained on the two islands was extensive, with 60 homes destroyed and another 214 homes suffering major damages. Saipan, capital of the northern Mariana Islands, was completely without power for several days (several weeks in some areas) and about 85 per cent of the water system stopped functioning. The Governor of the Northern Mariana Islands estimated that the damage totalled some $US 7 million. After the assessment was made, the President of the United States of America declared the area a major disaster area, qualifying it for federal disaster fund relief.

Other than the information provided above, no droughts or floods affected the islands of the Trust Territory during 1980.

T. VIET NAM

The Hydrometeorological Department Viet Nam reported the following information on damage caused by tropical cyclones and floods in Viet Nam during 1980.

1. Population

Deaths: 459

Missing: 37

Injured: 384

Deprived of flood, shelter: about 10 million

2. Housing

Buildings destroyed: 933,339

Buildings damaged: 103,934 (including 8,574 health centres, child-care centres and maternity centres)

3. Agriculture

Paddy crops totally destroyed: 534,000 ha

Paddy crops 50 per cent destroyed: 650,000 ha

Paddy crops 35 per cent destroyed: 225,000 ha

Paddy crops of reduced yield: 70,000 ha

Corn, potato, cassava plantations (85,194 ha): damaged produce estimated at over 2 million tons

Salt destroyed: 2,697 tons

Food-stuffs destroyed: 27,227 tons

Fertilizers lost: 81,166 tons

Buffalo, oxen killed: 4,800 head

Pigs killed: 700,000 head

Cattle killed: tens of millions

4. Industry

Hydraulic works and dams destroyed: 375 (value estimated at several hundred million dong)

Transport and fishing boats carried away: 9,253

Pumping stations damaged or destroyed: 150

Coal lost: 7,151 tons

Machine oil lost: 283 tons

V. METEOROLOGICAL REPORTS AND DAMAGE SUSTAINED IN 1979 AND EARLIER YEARS

A. AFGHANISTAN

A note on flood and hailstorm damage, 1979

The Ministry of Agriculture issued a summary statement of damage suffered during 1979 in Afghanistan from floods and heavy hailstorms. As reported to ESCAP by the Department of Irrigation and Maintenance of Canals and Dams, total damage in 1979 amounted to Af 1,556 million (equivalent to nearly $US 35.8 million at the January 1980 exchange rates).

The provinces experiencing flood and hailstorm damage were Kabul, Herat, Ghazni, Kandhar, Balkh, Somangan, Badakhshan, Takhar, Juzjan, Nimrooz, Farah, Laghman, Faryab, Baghlan, Helmand, Paktia, Kunar, Nangahar, Parwan and Luger.

The events caused the deaths of 11 persons and 6802 domestic animals, and the destruction of 60,640 houses. The reported damage extended to 54,846 jeribs of land (about 10,700 ha), 215 kilometres of canals and 75 kilometres of roads. Also affected were 24,400 tons of agricultural products and 18 million fruit trees.

B. LAO PEOPLE'S DEMOCRATIC REPUBLIC

Summary of the weather in 1979

The National Meteorological and Hydrological Service summarized the meteorological situation in Lao People's Democratic Republic in 1979 in a special communication to ESCAP. The Service, which is part of the Ministry of Agriculture, Forests and Irrigation, reports that the weather in 1979 was generally abnormal, bringing both drought and floods.

(a) *Rainfall*

The total annual rainfall was lower than usual; the average rainfall for the whole country represented 75.2 per cent of normal annual rainfall. The rainy season in 1979 began and ended earlier than usual.

Total 1979 rainfall in various regions of Lao People's Democratic Republic

Regions	*Total*	*Normal*	*Percentage of normal*
Viengxay	1 572 mm	1 452 mm	108.2
Xiengkhonang	1 465 mm	1 747 mm	83.8
Luang Prabang	1 200 mm	1 215 mm	98.0
Sayaboury	929 mm	1 341 mm	69.3
Vientiane	1 292 mm	1 708 mm	75.6
Savannakhet	1 120 mm	1 528 mm	73.3
Pakse	2 946 mm	1 894 mm	155.5

b) *"Dry spell"*

The "dry spell" in the middle of the rainy season occurred in July, lasting for some time in the regions of Vientiane and Sayaboury. Among the bad effects of this dry spell was that rice cultivation was adversely affected.

(c) *Temperature*

The average monthly temperature was higher than usual from the beginning of the mid-year period.

(d) *Tropical storms and floods*

Extraordinary rain and hailstorms occurred in the regions of Vientiane, Pakse and Khamouane during the last half of February. Tropical cyclones during the second half of June and August in the southern provinces of Savannakhet, Pakse and Attapeu, caused flooding.

(e) *Damage inflicted by drought and cyclone-induced flooding*

The year 1979 was one of both drought and floods, which affected the agricultural sector the most, particularly with regard to rice cultivation. The cultivated area affected by these natural disasters was 35,575 ha, out of a total cultivated area of 449,415 ha in the country. Losses in 1979 were comparatively less than those sustained in 1978.

C. REPUBLIC OF KOREA

Statistical review of damages resulting from meteorological disasters

The Central Meteorological Office of the Republic of Korea contributed the following statistical review of damage inflicted over the past one and a half decades by meteorological disasters.

The characteristic summer climate in the Republic of Korea is marked by a high temperature and humidity, and about half of the annual mean precipitation, with the result that floods frequently occur. The average annual amount of rain and related flood damage since 1916 have been estimated at about $US 51 million.

Table 1. The five years of greatest total damage by rains and related flooding, 1916-1976, Republic of Korea

Year	*Cause of damage*	*Loss of life (persons)*	*Submersion area (hectares)*	*Total amount of damage ($US 1 000)*
1925	Torrential rain, typhoon	517	191 647	170 023
1936	Torrential rain, typhoon	1 916	338 835	273 800
1959	Typhoon	781	236 808	166 211
1969	Torrential rain	562	115 111	176 306
1972	Torrential rain	682	166 237	150 622

Table 2. Types of causes of rain-related damage, 1916-1970, Republic of Korea

Type	*Number of times*	*Percentage of total*
Typhoon	133	28.7
Torrential rain	136	29.4
Developing cyclone	109	23.6
Heavy rain	41	8.9
Sudden gust	9	1.9
Tidal wave	9	1.9
Hail	14	3.0
Cold wave	12	2.6
Total	463	100

There has also been a loss of 247 lives on average every year. The five years of greatest damage inflicted by meteorological events since 1916 are listed in table 1, with damages estimated in terms of lives lost, cultivated land flooded and cost equivalent of losses.

Table 2 presents statistics on the various causes of rain-related damage for 1916 to 1970. As indicated, torrential rain, typhoons and cyclones were the main causes of rain-related damage which occurred in the Republic of Korea since 1916, representing 81.7 per cent of all categories of rain-related causes. Heavy snowfall and cold waves in winter were also significant factors, causing 11.5 per cent of the total damage.

River flooding occurs largely in the rainy season, between July and August. Since 1916, a total of 407 floods (44 per cent of the total flood events) have occurred during the month of July, and 694 floods (75 per cent of the total) have occurred during the combined months of July and August.

Table 3 presents figures for losses resulting from meteorological disasters in general, from 1964 to 1970. Table 4 gives annual estimates of damage from drought, from 1965 to 1979. Tables 5 and 6 give annual estimates of damage produced by floods and typhoons, respectively, from 1971 to 1979.

D. SOLOMON ISLANDS

A note on cyclone damages in 1979

The Ministry of Public Works and Utilities of the Solomon Islands has reported that only one cyclone caused any damage during 1979. Cyclone Terry occurred in February and its path covered the islands of South Malaita, Makira and Bellona. The damage caused on South Malaita was small, but on Makira it was quite severe totalling approximately $A 220,000) and on Bellona moderate (totalling approximately $A 30,000). Most of the damage was the result of the action of high winds and excessive rainfall on crops, houses, roads and bridges.

Table 3. Losses resulting from meteorological disasters in general in the Republic of Korea, 1964-1970

Year	Casualties			Public and private property damaged, by category							
	Dead	Missing	Affected	Houses (units)	Plantations (hectares)	Crops (tons)	Roads (sites)	Ships (units)	Bridges (sites)	River/ waterways (sites)	Harbour facilities (sites)
1964	395	277	107 489	7 751	16 320.51	33 337.56	1 816	1 332	467	868	197
1965	242	86	290 058	27 009	23 164.07	207 540.56	3 173	133	742	560	15
1966	128	29	163 687	10 179	10 288.29	135 316.02	2 955	1 501	483	550	84
1967	26	3	3 178	540	736.38	11 773.54	600	15	58	39	1
1968	127	47	66 098	5 698	3 796.61	569 [illegible]6.55	2 021	3 551	362	248	178
1969	562	137	341 875	29 546	17 650.72	402 974.23	4 880	889	724	1 725	190
1970	195	82	228 788	32 607	7 475.98	217 687.17	3 675	3 594	585	3 395	256

Source: Central Meteorological Office, Seoul, Republic of Korea.

Table 4. Annual estimates of damage caused by drought in the Republic of Korea, 1965-1979

Year	Rice		Dry field crops		Others		Total	
	Area affected (hectares)	Crops destroyed (tons)	Area affected (hectares)	Crops destroyed (tons)	Area affected (hectares)	Crops destroyed (tons)	Area affected (hectares)	Crops destroyed (tons)
1965	73 700.0	30 138.1	15 434.2	4 351.5	n	n	89 134.2	34 489.6
1966	15 618.0	11 199.7	9 868.0	1 256.6	19 371.1	43 953.4	44 857.1	56 409.7
1967	229 148.1	418 641.9	80 699.8	66 798.1	110 699.6	317 610.9	420 547.5	803 050.9
1968	310 279.7	531 349.5	107 105.4	196 957.0	53 037.5	127 605.4	470 422.6	855 911.9
1969	2 650.0	2 585.6	3 326.6	1 591.7	n	n	5 976.6	4 177.3
1970	359.1	282.2	5 656.3	3 712.8	n	n	6 015.4	3 995.0
1971	633.3	372.1	12 141.0	33 882.1	n	n	12 774.3	34 254.2
1972	3 224.4	4 809.4	10 320.9	9 157.0	n	n	13 545.3	13 966.4
1973	48 493.0	44 137.2	n	n	n	n	48 493.0	44 137.2
1974	n	n	n	n	n	n	n	n
1975	24 623.8	21 400.9	12 777.5	5 681.4	n	n	37 401.3	27 082.3
1976	41 043.8	13 115.9	920.7	550.9	n	n	41 964.5	13 666.8
1977	63 625.3	15 444.1	1 233.1	2 144.5	n	n	64 858.4	17 588.6
1978	28 457.5	19 402.8	18 752.0	15 642.7	n	n	47 209.5	35 045.5
1979	n	n	n	n	n	n	n	n

Source: Central Meteorological Office, Seoul, Republic of Korea.

Note: "n" denotes negligible damage.

Table 5. Flood damage in the Republic of Korea; annual estimates, 1971-1979

Year	Casualties			Public and private property damaged, by category							
	Dead	Missing	Affected	Houses (units)	Plantations (hectares)	Crops (tons)	Roads (sites)	Ships (units)	Bridges (sites)	River/ waterways (sites)	Habour facilities (sites)
1971	149	20	100 747	2 403	1 296.35	na	1 159	86	234	451	90
1972	667	121	59 751	26 706	15 327.55	112 120.24	3 861	167	122	1 913	35
1973	41	21	8 295	5 154	na	na	na	na	na	na	na
1974	26	94	29 067	1 857	658.48	113 270.98	491	26	165	679	9
1975	55	20	3 095	687	692.85	59 451.68	251	60	108	433	6
1976	88	55	6 748	931	1 934.59	18 248.00	522	53	179	260	4
1977	256	52	78 323	1 842	2 124.48	10 995.34	780	22	703	633	-
1978	37	12	6 004	694	299.17	10 180.17	321	15	40	388	12
1979	140	73	3 608	2 554	4 093.92	71 852.86	804	127	64	522	5

Table 6. Typhoon damage in the Republic of Korea; annual estimates, 1971-1979

Year	Casualties			Public and private property damaged, by category							
	Dead	Missing	Affected	Houses (units)	Plantations (hectares)	Crops (tons)	Roads (sites)	Ships (units)	Bridges (sites)	River/ waterways (sites)	Harbour facilities (sites)
1971	39	43	3 078	1 633	na	na	30	152			41
1972	11	43	3 084	3 248	1.90	271.77	109	240	1	6	168
1973	2	2	364	na	na	na	na	na	na	na	na
1974	21	11	5 173	618	1 171.83	10 950.98	392	44	82	355	49
1975	13	3	1 011	245	246.24	12 212.83	147	3	46	150	4
1976	34	336	1 904	266	34.22	4 744.90	159	687	26	208	128
1977	9	-	21	5	9.02	24.40	13	4	1	21 100	7
1978	21	13	7 928	1 264	1 342.99	22 077.10	429	139	64	323	78
1979	135	18	11 556	2 880	3 244.96	80 512.05	865	529	187	1 852	266

Source: Central Meteorological Office, Seoul, Republic of Korea.

Note: "na" means no data available.

VI. CONTROL OF TROPICAL CYCLONES, FLOODS AND DROUGHTS IN THE ESCAP REGION

A. TOPEX AND THE TYPHOON: MOBILIZING TO FIGHT AN AGE-OLD THREAT

Asian and Pacific countries have suffered the yearly ravages of tropical cyclones from time immemorial, involving untold losses of life and property. Member countries of ESCAP and the World Meteorological Organization have designed the Typhoon Operational Experiment (TOPEX) as a project to combat future losses. By improving forecasting and warning capabilities, TOPEX aims to reduce typhoon-related damages in its member countries, and to benefit all regions of the world affected by tropical cyclones.

TOPEX is an international effort to test systems of typhoon forecasting, warning and analysis in the western North Pacific. Set up in 1979 under the auspices of the World Meteorological Organization (WMO), the experiment involves a network of Asian and Pacific countries in the detection and tracking of typhoons over an area which includes Japan, the western rim of Asia as far south as the equator, and islands in the North Pacific (see figure 1). Instrumental to the success of TOPEX will be the co-ordinated collection and exchange of data from observations of actual typhoons in the affected countries, due to begin in 1981.

Three levels of activity comprise TOPEX: (a) the "core experiment", for trying out an integrated typhoon analysis-forecasting-warning system; (b) the "subexperiment", for improving techniques of forecasting the trajectory and intensity of a typhoon; and (c) national activities, for elucidating related phenomena, such as hydrological aspects, to be conducted by participating member Governments.

1. *Why TOPEX?*

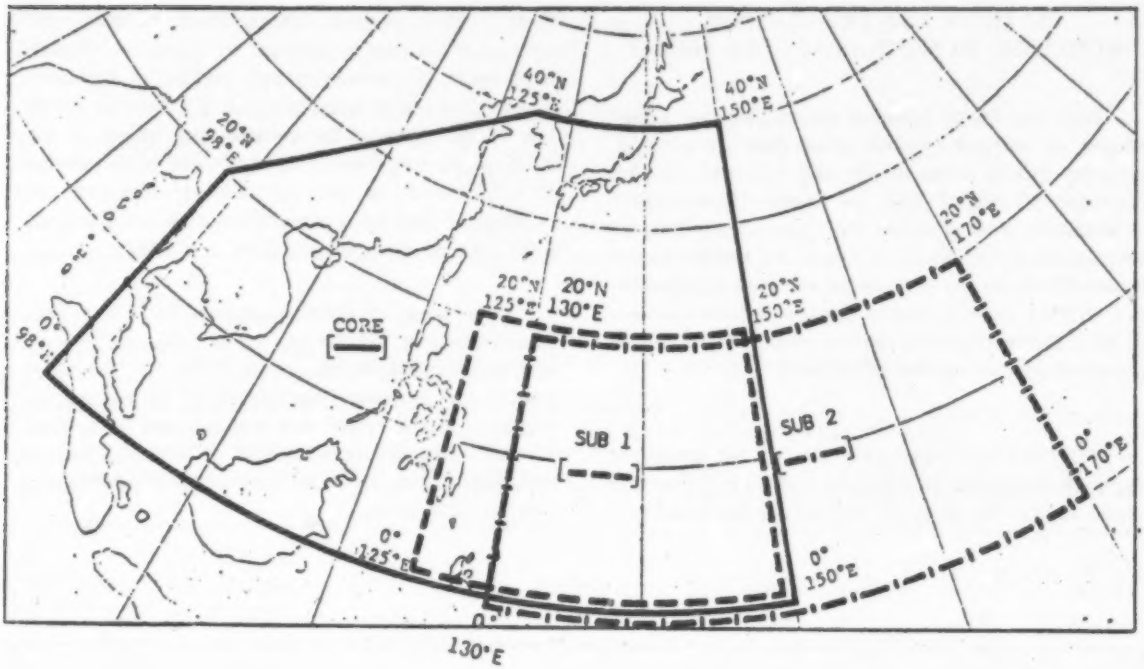
Tropical cyclones continue to take their toll of natural and human resources of countries in Asia and the Pacific each year. "The magnitude of these losses is not acceptable in a world increasingly dominated by fears of future economic disaster", warns an editorial in *TOPEX Newsletter* No. 4. Incomplete data for the ESCAP region give an estimate of $US 3,000 million per year in damages from tropical cyclones, over the 15-year period 1964 to 1979.

Major typhoon disasters in recent years have served to stress the importance of effective systems for (a) detecting, analysing and forecasting tropical cyclones; (b) predicting the effects of violent winds, heavy rainfall and storm surges which may cause flooding and landslides; (c) warning the public in good time; and (d) preparing people and disaster-related agencies to respond properly. Between all these systems there must exist adequate communication channels.

Do such systems exist in countries potentially threatened by typhoons? Have they been tested for effectiveness? Have they been tested in actual cyclone situations, and tested together as a whole system? These questions should be asked in each country if the level of preparedness is to improve in the region as a whole.

TOPEX has been organized to pin-point the areas where problems in these systems might exist, if at all, and what measures can be taken to combat disaster, in a real-time tropical cyclone situation. The regional scope of the experiment provides the means to examine the effectiveness of such systems within countries and between countries affected by a typhoon disaster.

Figure 1. Experimental areas for the TOPEX meteorological component



Notes: *Priorities for the subexperiment.* Special observing systems may be deployed, with the following priorities:

Priority 1. Studies of the development and movement of the typhoon. Typhoons appearing in the Sub 1 area of the experimental region (east of the Philippines: 0^{o} 125^{o}E, 20^{o}N 125^{o}E, 20^{o}N 150^{o}E, 0^{o} 150^{o}E) will be studied.

Priority 2. Studies of the generation of the typhoon. Typhoons appearing in the Sub 2 area of the experimental region (south-western North Pacific: 0^{o} 130^{o}E, 20^{o}N 170^{o}E, 0^{o} 170^{o}E) will be studied.

(a) *Long-term objectives*

TOPEX aims to reduce loss of life and damage to property as a result a typhoon winds, floods and storm surges, by improving the forecasting and warning capabilities of participating countries and by improving communication links (especially warning dissemination and information exchange) so that proper community response is ensured and necessary precautions are taken.

(b) *Scientific and technical objectives*

Improved capability in forecasting, warning and communication functions is expected to be achieved through fulfillment of the following immediate objectives.

The TOPEX participants will conduct tests on the various systems used for typhoon analysis, forecasting and warning, and on the systems used for disseminating these warnings and exchanging information on safety-related operations. These tests will be carried out on an operational basis during actual typhoon conditions. The observational programme and real-time exchange of typhoon data will be improved through intensified or new activities.

The performance of flood forecasting systems will be studied, and the most suitable forecasting models will be selected for use in flood-prone areas. Flood risk in potential disaster areas will be evaluated with the best available techniques.

The co-ordination of responsibilities among the various flood prevention and relief agencies will be studied and improved where need be, in the light of current knowledge of the technical and social aspects of flood prevention and mitigation of damage.

Warning dissemination systems will be upgraded and community participation will be enlisted as a measure especially in areas where existing communication media are poor. Public education and training programmes will be developed in order to ensure proper public response to typhoon warnings.

Originally these objectives grew out of views culled by the ESCAP/WMO Typhoon Committee in 1978. The Chinese Government suggested that typhoon experiments be carried out in the western North Pacific Ocean on just as large a scale as the concurrent Monsoon Experiment (MONEX), emphasizing the mutual exchange of knowledge and experience in forecasting and the mitigation of damage. At the eleventh session of the Typhoon Committee in October 1978, Japan supported these suggestions, and the Committee concluded that WMO should prepare and fund a plan for typhoon experiments in the western Pacific area.

Further discussions between the Central Meteorological Bureau of China, the Japan Meteorological Agency and the Typhoon Committee secretariat yielded a proposal for TOPEX which was submitted to the Eighth World Meteorological Congress, held at Geneva from 30 April to 26 May 1979. The Congress resolved that WMO member Governments, particularly those participating in the Typhoon Committee, should support TOPEX with any needed facilities in their respective countries, and with financial or technical assistance. During the rest of 1979 and 1980, the structure and activities of TOPEX evolved through discussions at technical and other meetings. TOPEX is being carried out as part of the ESCAP/WMO Typhoon Committee programme and as a subproject of the WMO Tropical Cyclone Project.

(c) *Management*

The Management Board for TOPEX was established in June 1980. Its terms of reference include provisions that the Board should manage all phases of TOPEX from the planning to the evaluation stages, and take all decisions necessary to achieving TOPEX objectives without need to refer to the Typhoon Committee.

Co-ordination of the three TOPEX components (meteorological, hydrological, communication) is achieved through a system of co-ordinators and country focal points. The co-ordinators stimulate activities in the various countries, monitor progress, provide advice and in general promote the TOPEX programme of work.

2. *TOPEX activities*

TOPEX will tackle its objectives in a three-part programme with meteorological, hydrological and warning dissemination/information exchange components in the various participating countries. The experimental programme is divided into a "pre-experiment" phase in 1981 and two "operational experiment" phases in 1982 and 1983. Figure 2 gives the detailed programme of TOPEX and related activities. The basic procedures and plans to be implemented are spelled out in the *TOPEX Operational Manual*, first compiled and published in 1980.

(a) *The meteorological component*

This component consists of the core experiment and subexperiment mentioned earlier. In the core experiment, all participating countries will follow common procedures for an integrated typhoon analysis-forecasting-warning system, using data obtained from an enhanced observational network in and around a typhoon. The observational systems to be used will be those surface and space-based subsystems designated under the Global Observing System of the WMO World Weather Watch Plan: surface to upper-air observations, and ships, radar, satellite and tide-gauge stations observations.

Figure 2. Schedule of TOPEX activities

1980	1981	1982	1983	1984
First planning meeting for TOPEX (17-26 June, Tokyo) (a) Establishment of TOPEX Management Board (b) Decision on implementation/operations plan for pre-experiment (c) Survey on commitments of participating members	Pre-experiment (29 July-18 August) Experimental operation of the management body for the first operational experiment, and examination and rehearsal of implementation of the observation and data management plans	Second planning meeting for TOPEX (February/early March, Tokyo) (a) Review and evaluation of pre-experiment (b) Decision on implementation/operations plan for the first operational experiment (c) Advice to IEC and ESCs	Third planning meeting for TOPEX (March) (a) Review and evaluation of first operational experiment (b) Decision on implementation/operations plan for the second operational experiment (c) Advice to IEC and ESCs	Evaluation meeting on on TOPEX (May) (a) Scientific and technical evaluation (b) Decision on future plans for international co-operation (c) Organization of a symposium or workshop on the results of TOPEX
Typhoon Committee, 13th session (2-8 December, Bangkok) (a) Endorsement of implementation/operations plan for pre-experiment (b) Guidance to TOPEX Management Board (c) Scientific lectures	Typhoon Committee, 14th session (10-16 November, Manila) (a) Confirmation of commitments to the first operational experiment (b) Evaluation of pre-experiment (c) Guidance to the TOPEX Management Board	First operational experiment (1 August-15 October) Typhoon Committee, 15th session (a) Examination of the report of the second planning meeting for TOPEX (b) Evaluation of the first operational experiment (c) Guidance to the TOPEX Management Board	Second operational experiment (1 August-15 October) Typhoon Committee, 16th session (a) Examination of the report of the third planning meeting for TOPEX (b) Evaluation of the second operational experiment (c) Guidance to the TOPEX Management Board	Typhoon Committee, 17th session Adoption of the final report of TOPEX for submission to WMO
Symposium on Typhoons (6-11 October, Shanghai)		Other related symposia/meetings	Symposium on advances in tropical cyclone research (tentative)	

The selection and number of typhoons for the experimental observations vary according to the different stages of TOPEX. Selection will be made on the basis of the expected lifespan (at least five days) and origin (preferably to the south of 15°N). Preferably, the tropical cyclone selected for study would be approaching the Philippines from the east, or be moving westward across the South China Sea. One typhoon will be selected for the pre-experiment in 1981, and two typhoons for each of the operational experiments in 1982 and 1983 (see figure 2).

The typhoons selected for TOPEX observation will be followed by scientists at the newly established International Experiment Centre (IEC) at Tokyo, and by Experiment Subcentres (ESCs) set up by participating countries in their own territories. Figure 3 shows the scheme of real-time information exchange between IEC and ESCs.

The subexperimnt involves obtaining detailed information on the three-dimensional structure of typhoons, how they are generated, and the process of their development and decay. The information will help in improving forecasting techniques for typhoon trajectories and intensities. This entire meteorological component will utilize the World Weather Watch network of facilities, as well as additional facilities required for the particular purposes.

(b) *The hydrological component*

The activities in this component are being individually implemented by participating countries. Existing systems for forecasting and warning of floods and storm surges will be evaluated by comparing their outputs with data from observed events in the field. TOPEX members will select simple deterministic forecasting models for their area, and the results will be compared in real-time forecasting operations. Flood risk associated with typhoons will be evaluated, particularly in relation to such hydrological effects as river and storm-surge flooding.

Member countries undertaking general assignments relating to the hydrological component include Japan, which will collect information from other TOPEX countries on their studies of flood-risk analysis, and on how these studies, together with flood-risk maps, are use in flood forecasting and warning operations. A report on this information will be circulated in 1982. The Philippines will compile information from some member countries on risks of storm-surge flooding and combined storm-surge/river flooding. The focus of this undertaking is to determine how these risks are computed and mapped, and how storm-surge and/or high-tide forecasts are interpreted in conjunction with flood forecasting. A report from the Philippines will be ready by the end of 1981.

(c) *The warning dissemination/information exchange component*

This last component is also being implemented individually in TOPEX countries. It deals with warning systems to promote safety of life and property during typhoons, and exchange of related operational information. Community preparedness and human response to warnings are included in this component.

The institutional measures which are recommended for action under this component include laws to cover formulation of a national disaster preparedness plan and a relief organization in each country, a clear definition of responsibilities of all agencies involved in warning and relief operations, and establishment of an emergency operations centre and a national co-ordination committee for all disaster-related matters.

Related technical aspects of these measures include a network of communications facilities for a warning service and for co-ordination of relief operations, designed to be serviceable under disaster conditions. Mass media programming should be enlisted in preparedness activities, and communication devices for community use should be supplied (e.g., sirens, torches, drums).

Social aspects of this component include plans for promoting community preparedness, such as evacuation and relief plans. Education campaigns through the mass media and by local instruction could increase awareness of how to deal with disaster situations and prevent damage as much as possible.

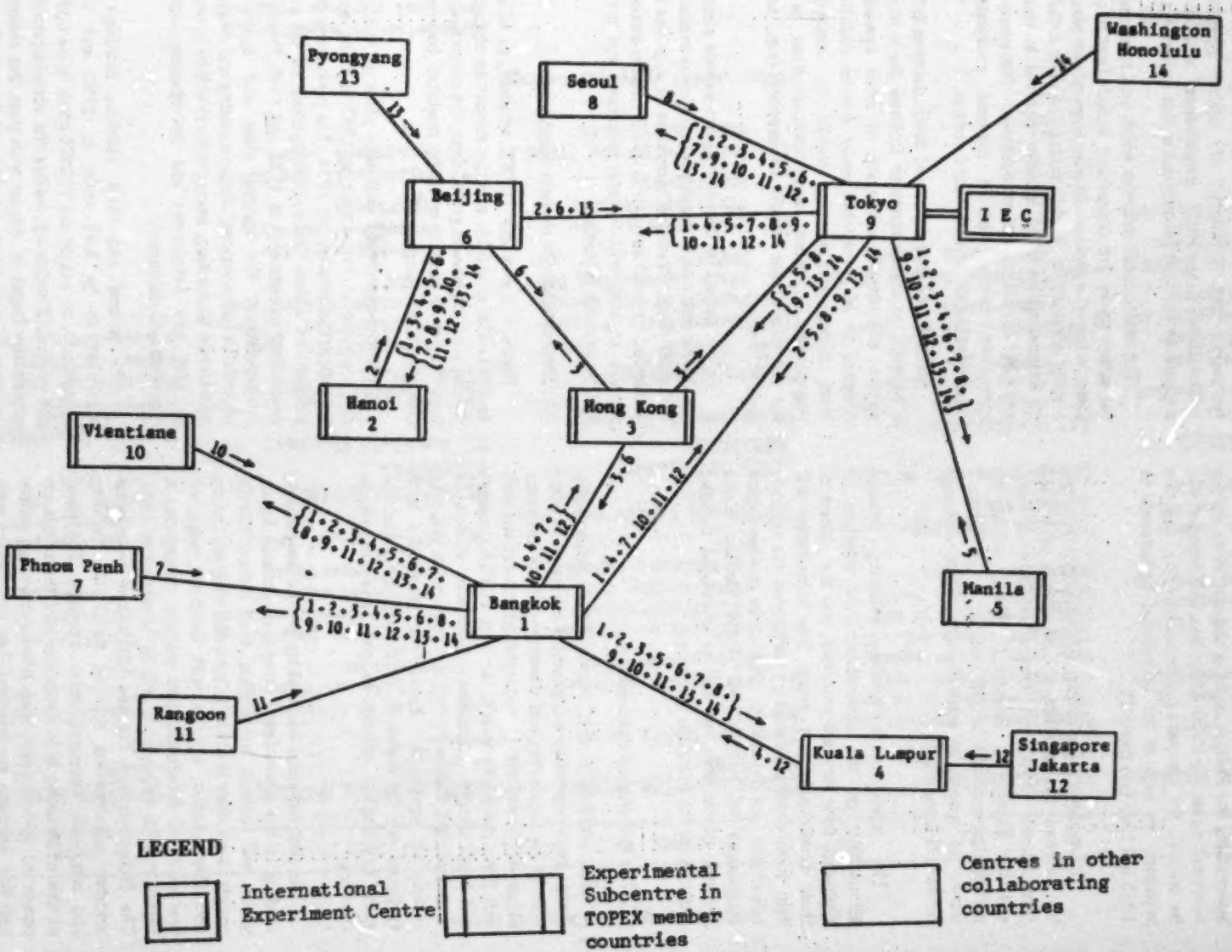
(d) *Time schedule for the experiment*

Figure 2 shows the TOPEX schedule, as of early in 1981. The time-table may be subject to changes in the light of experience gained from the pre-experiment in 1981, or it may have to be modified because of changing circumstances.

The pre-experiment will take place in 1981, the first operational experiment in 1982 and the second operational experiment in 1983. The pre-experiment is designed to ensure the smooth running of the actual operational experiments in 1982 and 1983. During the pre-experiment, the various plans and operational procedures (observational, data-processing and archiving, operational forecasting, among others) will be examined so that any deficiencies and discrepancies can be identified and eliminated.

The second and third planning meetings are scheduled to be held early in 1982 and 1983, respectively, to enable the TOPEX plans to be updated and revised, if necessary, before the actual operational experiment begins in August each year. An evaluation meeting is scheduled for May 1984 to allow the participating members to evaluate the results of TOPEX and decide on future action.

Figure 3. Exchange scheme for observational data and processed information among TOPEX participating country centres



(e) *Experimental areas*

Figure 1 shows those areas of the western Pacific Ocean designated for TOPEX meteorological activities.

The meteorological component involves different, overlapping geographical areas, which have been selected in keeping with the different objectives of the core experiment and subexperiment. The core experiment takes place within the area bounded by 0^{o} 98°E, 20°N 98°E, 40°N 125°E, 40°N 150°E and 0^{o} 125°E. The subexperiment has two areas of activity, whose boundaries are determined by the following points:

Sub 1 area: 0^{o} 125°E, 20°N 125°E, 20°N 150°E, 0^{o} 150°E

Sub 2 area: 0^{o} 130°E, 20°N 130°E, 20°N 170°E, 0^{o} 170°E

Experimental areas of the hydrological component have been selected by the respective TOPEX participating countries. Each participating country has designated an area on the basis of its susceptibility to flooding; river basin and sometimes coastal areas subject to storm-surge flooding are also included. The areas for hydrological activity are listed below (as designated by November 1980), but are not included in figure 1 because they are relatively small and scattered.

Country	*Designated river(s)*	*Area (km^2)*
China	Puyang and Xizhi Jiang	3 431 and 4 100
Japan	Yodo	7 281
Malaysia	Kelantan	11 914
Philippines	Pampanga	8 550
Republic of Korea	Han	26 218
Thailand	Pasak and Mae Klong	9 500 and 7 008

No specific country areas have been designated for the warning dissemination/information exchange component, since typhoon warnings might extend over a multinational area in each case.

(f) *TOPEX reference sources*

Detailed information on the TOPEX plan and programme of activities is contained in the following publications, which are available from the WMO secretariat, Case postale No. 5, CH-1211 Geneva 20, Switzerland.

TOPEX Report Series of the WMO World Weather Watch/Tropical Cyclone programme:

Report No. 1. *First Planning Meeting for TOPEX* (WMO No. 565; cost, 10 Swiss francs)

Report No. 2. *TOPEX Operational Manual*

Report No. 3. *Typhoon Operational Experiment--a General Description* (WMO N. 573; cost, 7 Swiss francs)

TOPEX Newsletter, published by WMO and ESCAP; No. 1 (Jan. 1980). No. 2 (June 1980), No. 3 (Nov. 1980 and No. 4 (April 1981)

B. FLOOD CONTROL IN THE ESCAP REGION

1. China: *Flood and drought damages and control measures in China*

Qiao Yucheng,
Ministry of Water Conservancy

China has a great number of rivers with abundant water resources. There are 1500 rivers with a catchment area exceeding 1000 km^2, which discharge a total of 270 million km^3 of runoff every year. The seven main rivers of the country include the Yangtze, Yellow, Huai, Hai, Pearl, Liao and Songhua.

China stretches over the high, medium and low latitudinal areas. The south-west summer monsoon brings humidity and rain, while dry weather with little rainfall comes from the north-west cold current. The annual average rainfall all over the country reaches 630 mm, but is unevenly distributed. For instance, the normal annual rainfall exceeds 1600 mm in the south-east coastal region, but is less than 200 mm in the north-west region. Half of the rainfall is concentrated in the rainy season of July, August and September, causing floods and waterlogging.

Typhoons from the north-west Pacific influence the weather of China. According to the statistics of the past 30 years, 858 typhoon events occurred in the western Pacific, 204 of which moved into China, averaging seven per year. Typhoons brought about benefits as well as disasters. Guangdong Province received the greatest number of typhoons and often suffered heavy losses.

(a) *Flood disasters before 1949*

Records show that there were 1029 heavy floods during the 2155 years between 206 B.C. and 1949 A.D., i.e. an average of one every two years. Major flood damages are listed in the table on the following page entitled "Major floods in recent Chinese history".

(b) *Flood control after 1949*

Action by local collectives, supported by the State, resulted in the building or strengthening of a

Major floods in recent Chinese history

River	*Year (A.D.)*	*Losses, effects*
Yellow River	1117	1 million people drowned
	1642	340,000 of the total population of 370,000 in Kaifeng City drowned
	1933	18,000 people drowned (lower reaches of the river)
	1938	12.5 million people affected, including 890,000 deaths; property losses up to 950 million ounces of silver (after Chiang Kaishek's troops broke the dyke at Huayuankou)
Yangtze River	1931	28.55 million people affected, including 140,000 deaths; 3.3 million ha of farm land inundated
	1935	Hankou region: 10 million people affected; 1.5 million ha of farm land inundated
Huaiho River	1921) 1931)	Flood disaster over the whole basin
Haiho River	1917) 1939)	Tienjing inundated
Pearl River	1915	Canton submerged for seven days, necessitating boat transportation in the city
Songhua River	1932	City of Harbin and large areas of farm land inundated.

total of 160,000 km of dykes and embankments, the building of 84,000 reservoirs with a total storage capacity of 400 million km^3 and the dredging of river courses to form flood depressions. These works reduced flooding to a certain extent.

Flood control on the main rivers was designed after the pattern of the heaviest floods since 1949. For instance, the Yangtze River flood works were designed against 1954 flood dimensions (the flood frequency of its tributary, the Jin-jiang River, is about once in 20 years, while Wuhan City is exposed to floods once in 100 years). The Huaiho River flood works were designed against the 1963 flood; river basins between the Huaiho and Haiho should be protected against expected flooding over a 50-year period. The Yellow River flood works were designed to protect against flooding of the 1958 proportions, which represents a frequency of once in 100 years. In any case, none of the rivers has ever had flood protection of the extent mentioned above.

From late in July to early in August 1963, a protracted belt of convergence of cold and warm air in northern China was turned into a rain belt 400 km long from north to south and 90 km wide above the Haiho River Basin, with rainfall of over 600 mm. In the centre, rainfall amounted to 865 mm in one day, 1457 mm in three days and 2050 mm in seven days. An area of 5560 km^2 was hit by a downpour of over 1000 mm. Through great effort by the civilian population and the army, and following the principle of "giving up local interests for the sake of the whole", Tienjing and the Tienjing-Pukou railway were protected from the flood at the expense of 3.8 million hectares of farmland and a 75-km section of the Beijing-Guangzhou railway line. Losses amounted to ¥RMB 6 billion, including ¥RMB 1 billion for relief and reconstruction.

Early in August 1965, typhoon No. 3 on the upper reaches of the Huaiho River brought an exceptionally heavy rain on the Hongru and Shaying river systems. Rainfall of 600 mm in three days and 400 mm in one day drenched areas of 8200 km^2 and 16,890 km^2 respectively. Linzhuang Hydrological Station in Miyang county, Honan Province, received a record rainfall of 1005.4 mm in one day and 1631.1 mm in five days. As a result the two big dams of Banqiao and Shimantan burst from the overflow of heavy floods, which washed away railway lines of 100 km and submerged 1 million ha of fields.

(c) *Summary of flood control measures and relief operations*

(i) Engineering projects

A large number of flood control projects have been built since 1949. They are effective to some extent, but it is impossible to achieve full prevention of flooding. In every flood season, people living along the river and the departments concerned must organize themselves

for a new flood emergency. By so doing, excessive flooding can be regulated to a reasonable extent and the losses reduced to the minimum.

(ii) Headquarters for flood control

The central headquarters for flood control takes charge of national flood emergency operations. Corresponding headquarters in provinces, prefectures and counties have been set up, and are responsible for the organization of emergency units, allocation of materials for precautions and maintenance of water projects. In case of heavy floods, joint army-civilian units are formed as well.

(iii) Co-operation

The interests of the various parts must be subordinated to the whole in the event of an extra-ordinary flood. A force of 1 million could be organized to build up the embankment while flood waters rise.

(iv) Relief aftermath

After a flood, the local authorities concentrate their efforts on developing production and rebuilding the homeland of the people in the affected area. The central Government provides relief funds, materials and food grains. Neighbouring areas will also lend support. For example, typhoon No. 13, in September 1979, brought heavy losses to some counties in the East River basin, Guangdong Province. Soon after, ¥RMB 30 million in funds, 4000 tons of steel, 20,000 tons of cement, 200,000 metres of cloth, 200 tons of nails and 10,000 tons of fertilizer were sent from the central Government to the disaster area.

(d) *Drought control measures in China*

Rainfall distribution in China is uneven. In the dry north-west of China, the annual rainfall is as little as 100 mm or less. Since the people understand that no water means no agriculture, they are inspired to organize water projects against protracted drought. Irrigation in Xinjiang Uygur Autonomous Region at present covers 85 per cent of the total cultivated land.

The uneven annual rainfall and typhoons in the central and eastern parts of China cause alternating flood and drought conditions. There are 1056 droughts on record during the past 2000 years, with only drops of rain recorded in some of the dry years. Since 1949, numerous water projects have been set up to vanquish drought and bring bumper harvests instead. Irrigation covers about 49 per cent of the total cultivated land in China. In 1978, an exceptionally serious dry spell hit Jiangsu Province. The Jiangdu pumping station lifted 30 billion m^3 of water into the drought-stricken fields; this is ten times the storage capacity of Hongze Lake. The harvest showed that the crop yield surpassed historical records in spite of the drought.

Nevertheless, 13 million ha are still liable to drought, including 6 million ha of reduced yields, because of insufficient protection and the changeable weather of China. The Government allocates funds to local areas for drought control every year.

2. India: *Some thoughts on flood control problems in India**

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Inundation of wide areas of flood plains of big river basins, especially in northern India, is a recurring feature. Several river commissions have been established to study the flood problems of various rivers and States and to suggest remedial measures. Such commissions have taken cognizance of conventional flood control measures, such as afforestation, soil conservation, improved agricultural practices, terracing, gully control and check dams, flood storage reserviors on tributaries and main channels, flood embankments, flood diversion channels, flood zoning, channel improvement in the flood plain as well as in the tidal reaches and clearing of bars and obstructions formed at the outfall at the sea end. Extensive literature has been published on all of these measures. This paper confines itself to highlighting certain aspects which need emphasis.

(a) *Types of rivers*

Rivers may be of different types, and a common approach to all of them may not be logical. The Ganga River, which forms the main drainage channel for the major portion of northern India, has well-developed tributaries which carry floods into the Ganga during the monsoon season. In contrast, the Gandak River is largely devoid of tributaries but gives out spill channels which become active when the main river brings down heavy floods. The different topography of these two rivers demands different approaches.

Another differentiation in river systems may be based on stability. Mature drainage systems such as the Ganga have achieved an equilibrium and reached stability both in plan and in elevation. On the other hand, the Kosi River has progressively shifted from east to west over a distance of about 70 miles in 200 years. In some rivers, lateral shifting may not be conspicuous, but the river-bed levels may rise, thus producing a rise in flood levels. The Brahmaputra in Assam experienced such a rise in the period following severe earthquakes

* Reprinted, with permission, from *Irrigation and Power* (Central Board of Irrigation and Power, New Delhi), vol. 35, No. 4 (October 1978), pp. 493-496).

in 1947 and 1950. The Indus River is also known to have raised its bed to a smaller extent, although the phenomenon has not been so closely linked with the occurrence of earthquakes in the catchment but has been the result of a deficient sediment-transporting capacity. River systems which are unstable have different characteristics from stable rivers, and would obviously need distinct and different approaches in formulating flood control schemes.

(b) *Rivers in different reaches*

The same river may have distinct characteristics in different reaches. These reaches may be broadly divided into the uppermost hilly reach, the submontane reach, the flood plains and, finally, the tidal reaches at the outfall into the sea. Each one of these reaches suffers from flood damage for different reasons and the remedial measures could therefore vary greatly from one reach to another, as discussed below.

(i) Hilly reaches

In the uppermost hilly reaches, the main problems are bank or toe erosion; instability of the hill slopes; damage to structures produced by boulders hitting against them; sediment deposition upstream of diversion structures, such as dams and barrages; and excessive sediment entry into the diverted water supplies.

The Teesta River upstream of the Sevok bridge in the West Bengal and Sikkim areas flows in a gorge and could be considered as a typical example of hilly reaches posing severe problems regarding toe erosion and instability of hill slopes. Various measures have been tried for the prevention of flood damage from the above two causes. For protection of the toe bank, apron revetment and provision of groynes and retaining and breast walls have been used. For additional stability for hill slopes, interception of surface runoff by means of cross-water drains, construction of masonry and concrete chutes, construction of check walls along the contour, provision of subsurface drainage, plantation of turf and vegetation and other means are normally tried. Several shortcomings of the above conventional methods have been noticed, however, requiring continued improvement in the present design and construction methods.

Damage to structural members and components, such as piers, sides of sluices and barrage gates, as a result of boulders hitting against them or of rolling and consequent abrasion, has been observed at several places. Provision of a top layer of granite blocks, which are more resistant to abrasion, and the use of high-strength lining with epoxy concrete or with structural steel members or full steel sheet lining, are common remedies found useful under such conditions.

To combat deposition upstream of diversion structures, the latest thinking suggests annual or periodic flushing of the deposited material, using low- or medium-flood flows of sufficiently long duration, and designing spillways or sluices to satisfy this requirement effectively, as is being considered for the Baira reservoir in Himachal Pradesh State.

An excessive amount of sediment entering into the irrigation and power supplies at the diversion works has posed serious problems in several projects. Settling tanks of different designs have been tried with success to separate out sediment and flush it back into the river.

(ii) Submontane reaches

Tendencies towards rapid aggradation and lateral shifting of river courses are common phenomena in submontane reaches. High-level bridges are known to have lost their waterway as a result of a rise in the river-bed produced by debris deposits. The bridge on the Jawai River on the Jaipur-Sikar section of the Western Railway in Rajasthan is an illustration in point. Civil engineering works in such areas of rapidly changing topography are always exposed to the possibility of becoming unserviceable. It is therefore better to leave such areas untouched, but if that is not possible, rapid aggradation and lateral shifting should be kept in mind as likely occurrences, and structures should be designed accordingly.

(iii) Flood plains

In flood plains, changes in meandering courses are quite frequent. Attempts at arresting such changes locally are found to have repercussions elsewhere. It is therefore desirable to tackle long reaches of the rivers in flood plains, as has been done in the case of the Mississippi in the United States. When such comprehensive training and protection works cannot be undertaken for any reason, attempts at arresting local changes should be confined to the *khadir* edges, leaving the river free to change meander patterns within *khadir* limits. The approach for rivers with flat meanders, such as the Ganga, must be different from that for rivers with acute meanders, such as the Burhi Gandak. Flat meanders move downstream, whereas sharp bends erode at the apex and become elongated, causing cutoff to develop at bottlenecks. In view of this, *khadir* limits must be delineated.

Flood embankments completely eliminate inundation in the flood-plain, and flood hazard is thus wholly checked. Inundation is, however, not wholly a curse. It is a boon as well, since it causes silt deposition, which has a high fertilizer value and results in more extensive and increased recharging of the ground water table. Areas subject to inundation on the banks of the Ganga River in the middle reach provide an illustration in point. On the other hand, embankments create drainage problems and serious flood hazards in case of breaches, as witnessed on the Kosi River downstream of the Bhimnagar barrage. The provision of flood embankments therefore cannot be considered the solution for flood problems under all conditions. In some situations, controlled flooding might be preferable and beneficial.

(iv) Tidal reaches and delta areas

Speedy disposal of storm or flood waters is a major problems in these areas. Widespread inundation could occur when high floods in the river synchronize with a high-tide level at the sea end. If the river flood discharge is reduced for any reason, the balance between the freshet flow and the tidal flow could be disturbed and siltation could occur, resulting in reduced capacity for the conveyance of river floods, reduced draft for navigation and more severe bar formation, which might require dredging. Diminished river flood volume could also result in the extension of the tidal prism, salinity intrusion and a high range of tides. At the outfall into the sea, such streams are prone to deposit sediment, and the tidal creek or estuary may open out into different channels at different times periodically. With continued sediment deposition, the delta at the sea end could extend far in the direction of the sea flood, as shown in the case of the Ganga, Brahmaputra and Indus rivers. Such changes present difficulties for navigational facilities.

Flood prevention in delta areas is achieved by the construction of embankments. River channel improvement is effected by dredging and by means of river training works. Augmentation of river flood discharges is also attempted under special circumstances.

(c) *Need for considering the entire river system in planning flood protection works*

As discussed in the foregoing paragraphs, flood problems vary in different rivers and in different parts of the same river. Such problems as river-bank or toe erosion might be local, and remedial measures might affect river conditions locally only. On the other hand, construction of flood embankments, river channel improvement by dredging and resectioning or the construction of reservoirs for flood storage are measures which bring about significant changes in river conditions over long distances. Dams are known to impound not only water but also a considerable amount of sediment, causing appreciable retrogression in the downstream reach. In the case of the Colorado River in the United States, such retrogression was experienced over a distance of more than 90 miles downstream of the Hoover Dam between 1935 and 1951. In the case of the Aswan High Dam on the Nile River in Egypt, a similar effect was observed and extensive studies are underway to gauge the possible repercussions of the Aswan High Dam on river-bed changes and other environmental aspects. The lowering of the bed levels as a result of retrogression could endanger the foundations of various structures in the river, and might also cause river bank erosion.

With embankments, the flood spread is confined and the area beyond is protected from inundation. Flood embankments also confine the sediment which used to be deposited on the areas beyond the banks. The net effect depends on the increase in the sediment-transporting capacity produced by the increased discharge within the embankments as compared to the increase in sediment input in the river discharge within the embankments. The sediment-transporting capacity is commonly found to increase in the post-embankment period.[1] This is because the sediment at higher levels, which previously spread over the flood plains, is normally of finer grade and therefore consumes relatively less energy for its transport.

River improvement works, such as resectioning or forming of cut-offs, are normally used in addition to the construction of embankments. Resectioning might also include measures for unifying several channels into a single stream, which helps to increase the sediment-transporting capacity. In addition, it is attempted to provide the river channel with a more regular section and at times to constrict it so as to produce an adequate draft for navigational purposes. When cut-offs are made, as in the case of the Mississippi, they are found to cause retrogression upstream and sediment deposition downstream until a new equilibrium is established.

All such changes produced by flood control measures must be assessed not only qualitatively but also quantitatively. Since the repercussions can extend over long distances, such investigations must be carried out over the entire reach likely to be affected. It has often been noticed that in the absence of such a comprehensive view, steps taken toward the amelioration of flooding may generate new problems. The co-ordination of development activities throughout the entire river basin and the drawing up of a master plan for the complete river system are therefore always advisable. Although adequate and proven methods for the quantitative estimation of the effects of flood control works may not exist, steps must be taken to ward off undesirable results in so far as possible, using past experience as a guide.

(d) *Need for research and development programmes*

The need for providing adequate design aid to river engineers is more acute in this than in other fields of engineering. In the field of flood control and river hydraulics there is a pressing need to concentrate research efforts on several problems. The field may be broadly divided into four parts: basic hydraulics, river morphology, training works and structures. Further subdivision is obviously possible. Before identifying research topics, the preparation of a state-of-the-art report is warranted. The research and development programme must cover not only laboratory experimentation, but also field observations supported by adequate

1 S.V. Chitale, "Sympathetic changes in river regime", paper No. 8032, *Proc. Inst. Civil Engineers, London*, part 2 (1977), pp. 621-622.

instrumentation. Development is also needed in the design and manufacture of improved equipment and techniques for the construction of flood control works and their maintenance. All such research and development activities need to be undertaken and co-ordinated by river and flood commissions, research organizations and others. The Central Board of Irrigation and Power is also concerned with this problem, and has set up a number of task forces which should bridge the existing gaps expeditiously.

Conclusions

Different types of rivers and various reaches of the same river suffer from different flood problems. Basic guidelines, as indicated below, are essential in identifying and attending to such flood problems.

Rivers may have a fully developed drainage system or have no tributaries and still be liable to give out spill during floods. Rivers may also be of the aggrading type, and thus unstable. Flood embankments are considered to be inadvisable as a long-term solution for aggrading types of rivers such as Kamla-Balan at Janzarpur in north Bihar. The river in this reach has been embanked and is known to be rising at the rate of about six inches per year. However, embankments may be ideal when rivers are relatively stable and have no tributary system, as in the case of the Gandak in north Bihar. With a fully-developed drainage system of tributaries, embankments would have advantages as well as certain disadvantages, and the pros and cons should be carefully weighed before the embankment scheme is accepted.

Submontane reaches are prone to suffer from aggradation as well as lateral shifting of channels. Such areas are better left alone; if some structure must be built, it should be designed with a view to the special characteristics of the submontane reaches of the rivers.

In flood plains, long reaches must be tackled simultaneously to avoid serious repercussions on isolated local works. When this approach is not feasible, protection works are better confined to *khadir* limits, which may be different and have different meander patterns.

Assessment of the effects of the flood control scheme is essential when constructing storage dams, flood embankments, flood diversion channels and river improvement works. Research and development programmes are necessary to bridge the gap in present knowledge in this respect. Improved techniques are also required, and should be tested during the construction and maintenance operational stages.

3. Malaysia: *Design of a flood forecasting procedure for the Klang River at Kuala Lumpur**

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ABSTRACT

A procedure was required for forecasting the flood level of the Klang River at Kuala Lumpur, Malaysia. On the basis of data from rainfall stations and tributary river stages, the flood stage may be predicted by means of a multiple-input, auto-regressive, moving-average linear model. This model was calibrated from storm records by means of stepwise multiple regression. The resulting set of equations was developed into a procedure for manual computation.

The city of Kuala Lumpur (the name means "muddy confluence" in Malay) is centred on the confluence of the Klang River and one of its tributaries, the Gombak. Parts of the city are prone to frequent flooding by the river, and the decision to mobilize flood relief services is based on the river stage measured at the Market Street bridge. In order to expedite flood relief it became desirable to have a method of forecasting Market Street river levels. As a compromise between the response time of the catchment and desired forecast times, a period of four hours was selected as the time between reception of input data and time of occurrence of the predicted stage. An essential requirement of the flood forecasting technique is that it can be computed manually with the aid of a battery-powered calculator. Night-time forecasting at short notice and possible loss of electric power rule out real-time computer use. However, the National Electricity Board IBM 360 computer was used to develop and calibrate the mathematical model.

(a) *Flood hydrology*

Malaysia has an equatorial climate and comes within the zone of influence of the north-east and south-west monsoons. The Klang catchment is protected from the south-west monsoon by the land mass of Sumatra, and from the north-east monsoon by the central mountain range of the Malay Peninsula. With the exception of rare "spillovers" from the north-east monsoon, most floods are caused by conventional storms which produce intense, but localized, rainfall. The frequency and intensity of these storms vary throughout the year and appear to reach a maximum in October and November, just prior to the onset of the north-east monsoon.

The catchment area above the Market Street bridge is 465 km^2. The lower part of the catchment has a high proportion of impervious urban areas, but the remainder

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of the catchment, up to the highest point at 1800 m, is covered with plantations and tropical rain forest. Because flood-producing convectional storms have a diurnal pattern, antecedent conditions were assumed to be the same for all events. The rainfall occurring in these storms is of such high intensity (up to 150 mm/h) that any inaccuracies in assumed loss rates have only a small effect on estimates of rainfall excess.

(b) *Data input*

The catchment can be divided into the three subcatchments of the Batu, Gombak and Klang rivers (figure 1). Within each subcatchment the Drainage and Irrigation Division (DID) has installed rainfall stations and a river-level gauge at the downstream end. In addition, there is a rain gauge in the city centre at the DID office, and river-level gauges at Market Street and at the water supply reservoir in the Klang subcatchment (figure 1). During a flood alert, observers send rainfall or stage readings by telephone or radio to the DID office. Observers are instructed to contact the office whenever the rainfall total during the day exceeds a certain value. On the basis of these rainfall reports the DID may alert the remaining observers, and data are sent in every hour until the stand-down instruction is given.

On the basis of some crude water balance estimates, an initial rainfall loss of 12 mm and a steady loss rate of 5 mm/h are used. These losses are applied to data from all rainfall stations except the DID office, for which zero losses are assumed for the impervious areas in the lower part of the catchment.

(c) *The model structure*

A mathematical model was developed for each subcatchment, relating the river stage at the bottom of the subcatchment to the rainfall data for the subcatchment. The river stage at Market Street was then related to the river stage for the three subcatchments. The model was broken into separate parts for several reasons. The subcatchment models should be calibrated separately, using the different storms which give the best estimates for each subcatchment. This is necessary because of the high spatial variability of convectional rainfall. Computation of the forecast in separate stages reduces the chance of calculation errors, and stage forecasts for the tributaries provide useful additional information on the possible flood hazard.

Since the river stage is the required information, the model relates stage rather than discharge to rainfall. This permits the use of river stations for which there are no rating curves. The model is used only at high river stages and for this restricted range all relationships are assumed to be linear.

A linear relationship between an input time series X_t and an output time series Y_t can be expressed with the least number of parameters by means of the auto-regressive moving-average (ARMA) process:

$$Y_t = A_o + A_1 Y_{t-1} + \dots A_p Y_{t-p} + B_1 X_{t-b} + \dots B_q X_{t-b-q+1} + N_t \quad (1)$$

where $A_o, A_1, \dots A_p, B_1 \dots B_q$ are model parameters, b is the delay time of the process and N_t is an error term. The calibration of ARMA processes is discussed by Box and Jenkins[1]. Much of the complexity of the fitting process arises from the reduction of the error (or noise) term N_t to a linear transformation of white noise. Since N_t is not pure white noise (i.e. errors of constant variance with no auto-correlation) the usual multiple regression techniques do not apply and the calibration is an iterative procedure.

The calibration of the flood forecasting model departs from an ideal analytical situation for the following reasons:

(i) The delay parameter b was set equal to the forecast period of four hours. Any runoff caused by rainfall during the forecast period, such as that from the impervious lower part of the catchment, became part of the forecast error.

(ii) The properties of the error term N_t are ignored to the extent that multiple regression techniques are used to calibrate the model. This permits the use of standard computer software by engineering hydrologists unfamiliar with the statistics of time series analysis.

(iii) Factors p and q, the number of auto-regressive and moving-average parameters, respectively, were determined using only one auto-regressive term, Y_{t-b}, and, using stepwise multiple regression, to find the required number of moving-average terms.

Equation (1) now becomes:

$$Y_t = A_o + A_1 Y_{t-4} + B_1 X_{t-4} \dots B_q X_{t-3-q} + e_t \quad (2)$$

where e_t is assumed to have the required properties for linear regression.

For each subcatchment the river stage is the output Y_t and there are several input rainfall stations, so that a multiple-input form of equation (2) is:

$$Y_t = A_o + A_1 Y_{t-4} + B_{11} X^{(1)}_{t-4} + \dots + B_{1q} X^{(1)}_{t-3-q} + \dots + B_{m1} X^{(m)}_{t-4} + \dots B_{ms} X^{(m)}_{t-3-s} + e_t \dots \quad (3)$$

1 G.E.P. Box and G.M. Jenkins, *Time Series Analysis Forecasting and Control* (San Francisco, Holden-Day, 1970), 535 pp.

The stage Z_t at Market Street is predicted from the forecasted stage in each of the three subcatchments by the equation:

$$Z_t = A_0 + A_1 Z_{t-4} + C_1 Y^{(1)}_t + C_2 Y^{(2)}_t + C_2 Y^{(3)}_t + e_t \quad (4)$$

which is also derived by means of multiple regression.

(d) *Calibration of the model*

A total of 39 storms was initially used to calibrate the model, which is periodically recalibrated as more data become available. Because of the different periods of record of the various hydrological stations, the subcatchments were calibrated with different numbers of storms: 6 for the Batu, 8 for the Gombak and 12 for the Klang. The stage correlation of equation (4) was derived from 12 events. Stepwise multiple regression was permitted to run until all variables were included. Variables which had entered the regression were not allowed to be rejected subsequently. The criteria for inclusion of a variable were that it gave a significant decrease in error variance and did not cause oscillations in the regression coefficients. Serious oscillation of the coefficients indicates inter-correlation of variables, which means that little new information is being added to the regression.[2]

A set of coefficients from a calibration is shown in table 1. The absolute values of the coefficients are not important because they are the result of using a mixture of metric and British units for the input data (the Malaysian metrication programme was still in progress). Their relative values, however, show that the weighting of the coefficients is reasonably smooth. The values of the intercept term are the result of all river stages being measured with respect to mean sea level.

(e) *Application of the procedure*

In order to facilitate the manual computation of the four equations required for the forecast, a cardboard template was constructed (figure 2). The template was designed for use with standard computer-printer paper. The headings on the template are used as a guide for ruling up the required columns in which the input data are recorded as each station reports. When the template is placed over the data with the time slot aligned correctly, the data values appear in the slots adjacent to the appropriate coefficient. The multiplications and additions can then be carried out with the aid of a calculator, or entirely by hand.

2 J. Johnston, *Econometric Methods* (New York, McGraw-Hill, 1963), 300 pp.

Forecast equation coefficients

Station		*t*	*t-4*	*t-5*	*t-6*	*t-7*	*t-8*	*t-9*	*t-10*	*t-11*
			Batu subcatchment							
Tua River			0.74	0.13	0.36	0.53	0.53			
Kepong			0.44	0.50	0.49	0.35	0.29			
DID Selangor			0.99	0.35						
Sentul Bridge		F/C	0.72							
Intercept value	=	28.93								
			Gombak subcatchment							
Gombak mile 13						0.16	0.15	0.12	0.15	
DID Headworks			0.60	0.48	0.51	0.51	0.40	0.36	0.28	0.18
DID Selangor			0.13	0.12	0.13	0.14				
Pekeliling Street		F/C	0.78							
Intercept value	=	21.40								
			Klang subcatchment							
DID Ampang			0.27	0.29	0.24	0.21	0.17			
Klang Gates			0.29							
Kampong Baru		F/C	0.81							
Intercept value	=	18.69								
			Market Street forecast							
Sentul Bridge		0.17								
Pekeliling Street		0.69								
Kampong Baru		0.35								
Market Street		F/C	0.15							
Intercept value	=	-43.71								

Note: F/C = value is forecasted.
The time unit is one hour.

Figure 1. The catchment of the Klang River at Kuala Lumpur

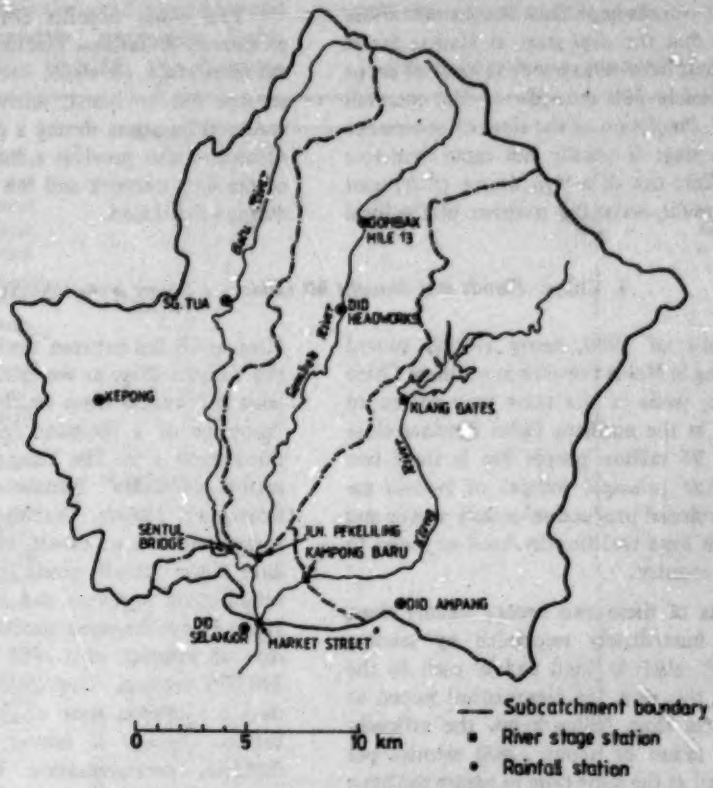
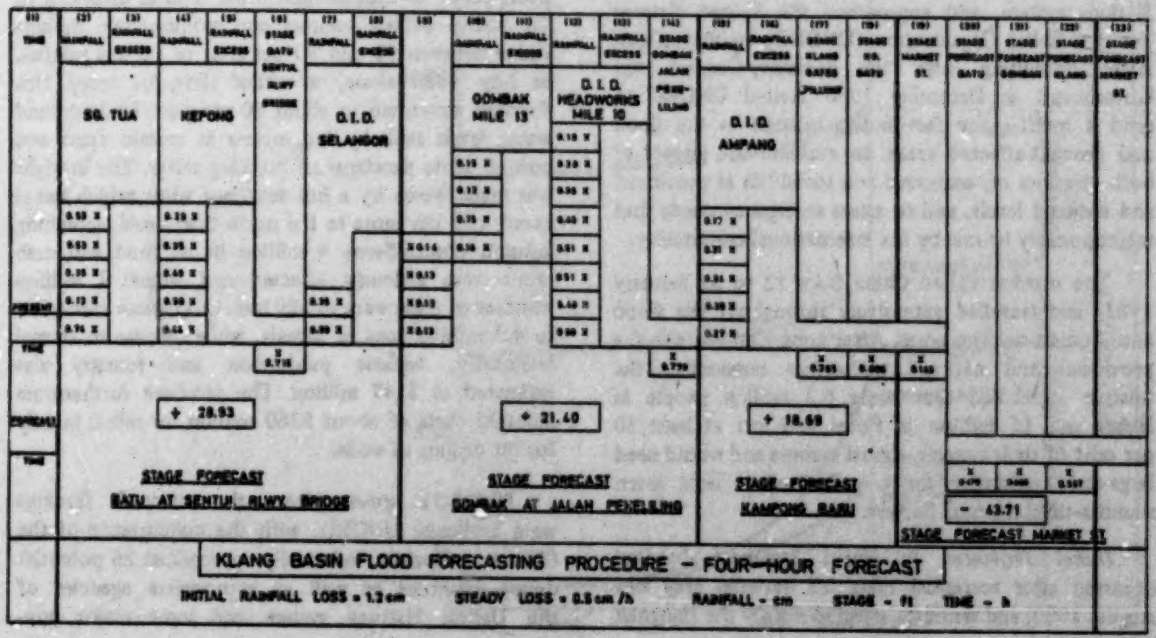


Figure 2. The template used for flood forecasting



(f) *Results*

It is difficult to anlyse the errors of the procedure because of the assumptions made in the mathematical structure, the method of solution and the nature of the data. Forecast records kept since the procedure has been in use show that the river stage at Market Street can be predicted four hours ahead with an error of about 300 mm in a possible 900 mm rise or 600 mm fall during the period. Prediction of the time of occurrence of the maximum stage is usually not more than two hours in error. While not of a high degree of forecast accuracy, these results serve the purpose of the local authorities. Any significant improvement in accuracy cannot be expected because of the effect of runoff from the city area, which can cause changes in the river stage within the four-hour forecast period.

Two other benefits derive from the forecasting procedure. A national method for making estimates of the river stage, on which decisions to alert flood relief services can be based, relieves the decision-maker of considerable stress during a period of emergency. The procedure also provides a framework for the planning of the data network and the organization of observers during a flood alert.

4. China: *Floods and drought hit China -- a report from UNDRO*

In the middle of 1980, heavy rainfall caused widespread flooding in Hubei Province in southern China west of Shanghai, while at the same time prolonged drought occurred in the northern Hebei Province close to Beijing. Some 95 million people live in these two provinces, and their principal sources of income are derived from agricultural production--mainly cereals and rice--part of which have traditionally been exported to other parts of the country.

As the effects of these two events became clear, the Government immediately responded by sending large amounts of relief in kind and in cash to the affected areas. In this way, the Government hoped to prevent food intake from falling below the officially established grain ration of about 1,400 calories per person per day, and at the same time to ensure the basic needs of those people who had been suddenly deprived of their belongings or of a major part of their average annual income. However, the needs were such that further help was needed, and the Government for the first time sought relief assistance from the United Nations system, and approached the United Nations Disaster Relief Organization (UNDRO) to that effect. After consulting with the Secretary-General, the Government in December 1980 invited UNDRO to send a multiagency fact-finding mission to the flood and drought-affected areas, to evaluate the impact of both disasters on economic and social life at provincial and national levels, and to assess emergency needs that might possibly be met by the international community.

The mission visited China from 12 to 31 January 1981, and travelled extensively throughout the flood and drought-stricken areas. After consultations with the provincial and national authorities concerned, the mission concluded that some 6.2 million people in Hubei and 15 million in Hebei had lost at least 50 per cent of their average annual income and would need large-scale assistance for a period of at least seven months--until the next harvest.

Hubei Province. In Hubei Province, flooding occurred after torrential rains fell between May and August 1980, and seriously affected mainly the Jianghan Plain which lies between the Han River in the north and the Yangtze River in the south. The Plain has numerous lakes and smaller rivers which earned Hubei the name of "province of a thousand lakes". It is traditionally a flood-prone area. The Yangtze itself is known as "the sorrow of China" because of its frequent flooding throughout history. Drainage is achieved by a wide-spread network of canals, but in general flood waters have little run-off possibilities. This creates serious waterlogging problems and increases soil salinity. Last year's floods damaged almost 900,000 ha of cultivated land so seriously that total crop failure occurred on 390,000 hectares. Crop losses were estimated at more than 2.5 million tons of grain and 130,000 tons of cotton. Damage to houses, school premises, health facilities, communication lines, roads and hydro-electric power stations was also severe and was calculated at well over $US 150 million.

Hebei Province. Hebei is one of the five most populous provinces in China, and it is also comparatively poor, prone to drought and other natural disasters. In the course of last summer and autumn, rain deficits varied between 30 and 80 per cent of normal rainfall. In July 1980 alone, a critical time for crops, this shortfall amounted to about 60 per cent. Underground water levels sank by ten metres in certain areas and created acute shortages of drinking water. The drought was made worse by a hot southern wind, which swept about 150 km more to the north than usual, scorching autumn crops. Some 4 million ha of food and cash crops were seriously affected and almost 1 million hectares of grain were totally lost. Crop losses amounted to 4.5 million tons of cereals, while damage to animal husbandry, aquatic production and forestry was estimated at $147 million. The province furthermore incurred costs of about $260 million for relief, mainly for the digging of wells.

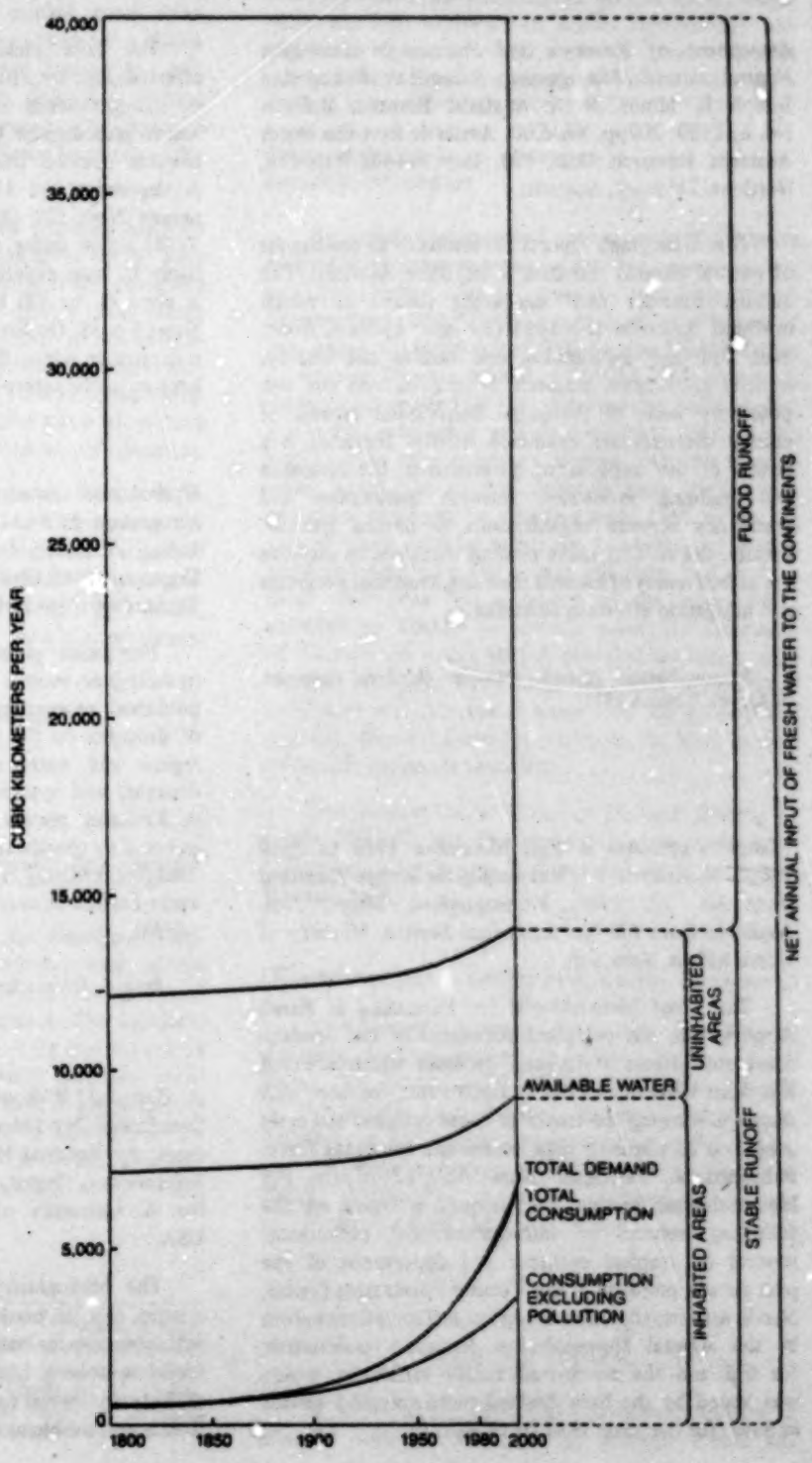
UNDRO's appeal. Once the mission's findings were available, UNDRO, with the concurrence of the Chinese authorities, informally approached 26 potential donor countries as well as appropriate agencies of the United Nations system and some major non-

governmental organizations, to ascertain their interest in assisting China to alleviate the hardship caused by both disasters. On 23 March 1981, UNDRO launched an official appeal for food aid, seeds and implements to restore agricultural production, and medicines and medical supplies to maintain appropriate health standards. By May 1981, UNICEF, the European Economic Community and the Governments of Australia, Japan, Norway and Sweden had already announced sizeable contributions, while a number of other important donor countries had indicated that they would also respond to the appeal.

Source: *UNDRO news*, May 1981

GLOBAL WATER SUPPLY consists mainly of the base flow, or stable runoff, of rivers and streams. Of the net continental influx of 40,000 km^3 per year all but about 12,000 km^3 runs directly to the sea in floods. A small fraction of the flood water can now be captured by dams, so that by the end of the century the stable and regulated runoff will amount to 14,000 km^3. Of this amount, however, some 5,000 km^3 flows in sparsely inhabited regions, such as rain forests; hence the total volume of water readily available at the end of the century will be about 9,000 km^3 per year. Actual consumption then will be about 3,500 km^3, but water made unusable by pollution will effectively add another 3,000. Total demand, which includes requirements for water that is not consumed but must still be made available, will reach almost 7,000 km^3 per year.

Source: R.P. Ambroggi, "Global water supplies", *Scientific American* (September 1980).



VII. PUBLICATIONS AND NEWS FEATURES OF REGIONAL INTEREST

RECENT PUBLICATIONS

Assessment of Research and Practice in Australian Natural Hazards Management. Geoffrey Pickup and Joseph E. Minor. North Australia Research Bulletin No. 6, 1980. 207pp. $A 6.00. Available from the North Australia Research Unit, P.O. Box 39448, Winnellie, Northern Territory, Australia.

This monograph reports the results of an assessment of natural hazards activities in northern Australia. The authors consider each significant hazard to which northern Australia is subject (drought, cyclone, flood, bush fire and earthquake) and outline the history, current knowledge, research in progress and the risk posed by each to Australia. Behavioural aspects of natural disasters are examined briefly. Included is a review of the response of governments, the insurance and building industries, research institutions and emergency services organizations to natural hazards. Finally, the authors make recommendations to improve the effectiveness of hazards planning, technical programs and mitigation efforts in Australia.

Source: *Natural Hazards Observer* (Boulder, Colorado, USA), vol. 3, March 1981.

"Tropical cyclones in Fiji, November 1969 to April 1980". R. Krishna. Fiji Meteorological Service *Technical Note No. 13.* 1980. Mimeographed, 38pp., illus. Available from Fiji Meteorological Service, Ministry of Home Affairs, Suva, Fiji.

The Chief Meteorologist for Forcasting at Nandi Airport, Fiji, has compiled summaries of the development and effects of tropical cyclones which affected Fiji from November 1969 to April 1980, together with diagrams showing the tracks of those cyclones and areas subjected to winds of gale, storm and hurricane force. Published as *Technical Note No. 13* of the Fiji Meteorological Service, the account is based on the following sources of information: (a) preliminary reports on tropical cyclones and depressions of the past decade prepared at the Weather Forecasting Centre, Nandi Airport, (b) information on earlier cyclones given in the Annual Meteorological Summary publication for Fiji and the south-west Pacific territories, which was issued by the New Zealand meteorological service at Suva (for the years 1947 to 1970).

The note includes all tropical cyclones which affected Fiji, i.e., those believed to have caused gales or stronger winds in the Fiji area. Some depressions which caused gales but evidently did not acquire full tropical cyclone characteristics have been excluded. A depression on 11 January 1970 and depressions named Nora (29 October 1970) and Tina (26 April 1974) come under this category. A list of the areas likely to have experienced gales from these depressions is given in the Fiji Meteorological Service Information Sheet No. 59. On the other hand, Wally, which remained a depression while affecting Fiji, deserved to be included because of the severe flood damage it caused.

Hydrological Aspects of Droughts. Proceedings of a symposium held 3-7 December 1979 at New Delhi, India. Available from: Professor Subash Chandra, Department of Civil Engineering, Indian Institute of Technology, New Delhi 110 019, India.

Forty-nine papers from the 1979 symposium on hydrological aspects of droughts are included in the published proceedings, on such tropics as the effects of droughts on the morphology of land regime, water regime and water quality, trends and prediction of drought, and systems management. A key paper, by A. Krishnan, gives a definition of droughts and factors relevant to specification of agricultural and hydrologic droughts, utilizing computation of the daily or weekly water balance instead of the less meaningful criterion of rainfall.

Source: *International Water Report,* Autumn 1980.

A Selected Bibliography on Disaster Planning and Simulation. David Morton. 1981. 36pp. $US 2. Available from the National Hazards Research and Applications Information Center, Institute of Behavioral Science No. 6, University of Colorado, Boulder, CO 80309, USA.

The bibliography contains about 80 entries on articles, reports, books, periodicals and studies that deal with planning for natural disasters and with simulations useful in solving hazard problems. Although it covers all hazards, special sections are devoted to earthquakes, floods, and problems in coastal zones.

RESEARCH BRIEFS FROM THE UNITED STATES OF AMERICA

"Instant replay" photo aid to hurricane analysis

Stereo-imaging photographs of hurricanes may provide weather forecasters with routine, quick time-lapse views of ongoing storms. Developed by a NASA Goddard Space Flight Center team headed by A.F. Hasler and E.B. Rodgers, the technique utilizes photographs taken by two different geosynchronous satellites which hover over two different locations of the earth.

Cloud-cover photographs taken simultaneously by the satellites of Hurricane Frederic in 1979 were remapped by the scientists in a computer and combined for stereo display and analysis. Photographs taken during a period of several hours and combined in a time-lapse sequence were found to display significant changes, such as those that occur in the storm's dense cloud cover. From the stereo height observations of this overcast, and other satellite data, estimates of the storm's intensity can be made.

Dr. Hasler reported on the new technique at the Thirteenth Technical Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society. The new technique takes only a few hours, compared with previous analysis which took several months.

Source: *Water Newsletter*, 29 December 1980.

The overfly approach: cyclonic intensity determination by jet overflight

An article in the *Bulletin of the American Meteorological Society** suggests that determination of the intensity of tropical cyclones is possible through upper-tropospheric jet aircraft reconnaissance. The cyclone's upper-level temperature anomaly and its gradient can be related to surface pressure and wind, and may prove as reliable a measure as that which low-flying propeller-driven aircraft can provide. Such measurements are likely to yield more reliable data for cyclone intensity determination than satellite observations of cloud configuration.

Only the normal aircraft instrumentation for measuring temperature and pressure-altitude is required. Jet flights have the advantage of greater speed, longer range and less turbulence (if echoes are avoided) than flights by propeller craft, and in most countries relatively more jet craft are available for such missions.

New project follows up on disaster assistance information

An information-oriented project entitled "Disaster assistance information management" has been sponsored by the United States Agency for International Development (USAID) in order to build on a system of data bases produced since 1976 for the USAID Office of Foreign Disaster Assistance (OFDA). The system is designed to provide OFDA with base-line demographic, economic, geographic and socio-political data for the world's most disaster-prone countries, and with a world-wide history of natural disasters since 1900, with particular emphasis on disasters since 1965 where the United States provided assistance. In addition to revising those two data bases, the project will design and produce three new ones: (a) a record of the commodities provided by USAID for disaster relief; (b) summaries of disasters for which OFDA provided assistance, with break-downs of other bilateral and international assistance, and (c) special reports of conferences and regional disaster assistance activities, as well as lists of disaster assistance specialists.

The project has a 12-month life and funding of nearly $US 250,000. The project manager is Ms. Lucy S. Drobot of Evaluation Technologies, Inc., Arlington, Virginia, USA.

Drought: two papers address basis research questions

Introductory extracts from two articles on droughts, both co-authored by John A. Dracup, Kil Seong Lee and Edwin G. Paulson, Jr., of the School of Engineering and Applied Science, University of California at Los Angeles, appear below. The full articles were originally published in Water Resources Research *(ISSN 0043-1397; American Geophysical Union), vol. 16, No. 2 (April 1980), pp. 289-301.*

On the definition of droughts
(Paper No. 9W1439)

In the current hydrologic literature, devising a suitable universal definition of drought events has

* Vol. 60, No. 9, September 1979. "Tropical cyclone intensity determination through upper-tropospheric aircraft reconnaissance", by William M. Gray of the Department of Atmospheric Science, Colorado State University, Ft. Collins, Colorado, USA. American Meteorological Society. For reprints, order 0003-0007/79/091069-06 ($US 5.50).

proven to be an abstruse task. Yevjevich has stated that the failure to develop a succinct and objective definition of droughts is one of the principal obstacles to the effective investigation of these events.

In a broad sense, the problem of drought definition is caused by the conflicting concepts held by a variety of academic fields of study. For example, the hydrologist is concerned with drought in the context of a period of below-normal streamflow and depleted reservoir storage; the meteorologist is concerned with drought in the context of a period of below-normal rainfall or snowfall; the agriculturalist is concerned with drought in the context of a period during which soil moisture is insufficient to support crops; and the economist is concerned with drought in the context of a period of low water supply which affects society's productive and consumptive activities. In addition, the concept of drought varies among regions of differing climates. In Bali, any period of six days or more without rain is considered a drought, while in Libya, droughts are only recognized after two years without rain.

Although the preceding drought concepts differ in many ways, they all require the analyst to consider a certain set of decisions in order to define accurately the type of drought event to be studied. This set of decisions consists of the following:

(a) Is the primary interest in precipitation (meteorologic drought), streamflow (hydrologic drought), or soil moisture (agricultural drought)?

(b) What is the fundamental averaging period of the time series to be studied (e.g. month, season, or year)?

(c) How are drought events distinguished analytically from other events in the time series?

(d) How are the regional aspects of droughts to be considered in the study?

This paper deals with the implications of each of these questions as they relate to the issue of drought definition. The specific decisions made by an analyst will be a function of his point of view and the intent of his analysis. The choices available are identified, and the impacts of various alternative drought definition decisions on possible analyses to be performed are discussed. A drought definition is then selected to be utilized in the frequency analysis for multi-year hydrologic droughts.

In this paper, droughts are considered to have three components: duration, magnitude (average water deficiency), and severity (cumulative water deficiency). The implications of the definition of drought upon these three parameters are evaluated herein.

On the statistical characteristics of drought events

(Paper No. 9W1440)

Knowledge concerning hydrologic drought (extended periods of below normal streamflow) is an important aspect in the planning of water resource systems and in the allocation of available stream flows among a variety of competing uses. However, the study of droughts in terms of duration, magnitude (average deficit), and severity (total deficit) is one of the most seriously neglected aspects of the science of hydrology. Relatively, little attention has been given to the quantitative and qualitative aspects of drought analysis. Much of the existing drought studies refer to specific basins or particular historical droughts. Notable exceptions, however, include Huff and Changnon, who have developed a method of estimating drought streamflow frequency by using low precipitation frequency and a single geomorphic index; Whipple, who has applied the station-year method of regional frequency analysis to multi-year hydrologic droughts; Yevjevich, who has applied the statistical theory of runs to the analysis of drought events; and Askew *et al.*, who have observed that existing synthetic streamflow generation models fail to reproduce accurately historical critical periods.

A thorough understanding of drought parameters is required for the development of a stochastic model that will generate drought events and would be useful in devising valid methods of performing regional drought frequency analysis.

In this paper, several statistical tests are performed on streamflow series for purposes of analysing multi-year drought events. These statistical tests on both high-flow and drought event parameters include (a) stationarity in terms of their linear trend; (b) randomness in terms of lag-1 serial correlation; (c) correlation and cross correlation berween these parameters (duration, magnitude and severity). The test results and their implications are discussed in relation with the characterization of high-flow and drought event series. Two types of envelopes for drought duration and severity are presented which use Tschebycheff's inequality. These envelopes give an excellent indication of the maximum response of a watershed in terms of drought duration and severity during the period of record.

Reprints of the original two articles are available on request from the American Geophysical Union, Separate Sales Dept., 2000 Florida Avenue NW, Washington DC 20009, USA. The first reprint in an order costs $US 3.50, and additional reprints are $1.00 each.

THE TSUNAMI THREAT -- CURRENT INFORMATION AND RESEARCH ACTIVITY FROM *NATURAL HAZARDS OBSERVER* (MARCH 1981)

Information services

To encourage research on the potentially catastrophic tsunami, the United States National Geophysical and Solar-Terrestrial Data Center (NGSDC) has compiled a set of data bases pertinent to the understanding of tsunamis. Located in Boulder, Colorado, the NGSDC is operated by the United States National Oceanic and Atmospheric Administration, under the Environmental Data and Information Service.

The available data include digital and analog seismograms from a world-wide network, and indication of epicenter, magnitude and focal mechanisms; mareographic information from tide records; digital bathymetric figures; and reports on tsunami effects as well as a photographic file. The centre has published catalogues on tsunamis in Alaska and Hawaii, It also operates a modest guest worker program and can provide space, access to computers, digitizers, plotters, data files, and some financial help to researchers. Data can be obtained at the cost of copying, or by exchange with scientists who deposit records in the centre.

For further information, contact Ms. Patricia Lockridge, NOAA, EDIS/NGSDC, D622, 325 Broadway, Boulder, CO 80303, USA.

Research project on Tsunami risk

A project entitled "Pacific region tsunami threat analysis" will examine several locations on the coasts on Peru and Chile to estimate the potential for tsunami generation, should large earthquakes occur there. Working with seismologists to assess seismic potential in the areas, the researchers will also use historical evidence to build scenarios of the types of earthquakes most likely to happen. From those will result possible bottom displacement patterns and a numerical tsunami model. The simulation of surface wave generation and propagation will allow the determination of the types and degrees of tsunamis possible in the region.

The project is supported by the United States Agency for International Development (USAID), Office of Foreign Disaster Assistance, over a five-month period with a grant of about $US 30,000. The principal investigator is Gerold T. Hebenstreit of Science Applications, Inc., MacLean, Virginia, USA.

Tsunami visions

Catalog of Tsunami Photographs. John B. Nelson. United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service. Key to Geophysical Records Documentation (KGRD) No. 13. 1980. 52pp. $US 3. Available from the National Geophysical and Solar-Terrestrial Data Center, NOAA/EDIS, Boulder, CO 80303, USA.

The thirteenth publication in the KGRD series lists approximately 600 photographs of tsunamis and their destructive effects. The catalogue contains over 80 examples of available photos and provides a price list of anyone wishing to obtain black and white or color prints, copy negatives, and transparencies. Nine tsunami events occurring during the years 1946-1975 are represented in the collection. Persons may request materials by either reviewing the captions or by specifying a location of interest, quality of photograph, or specific subject matter.

Water use -- the high, hidden cost of living

The water bill for a typical breakfast of eggs, bacon, buttered toast and milk amounts to about 510 gallons of water. Production requirements, not including water used in harvesting, processing, transportation and home preparation, for other items in the daily diet include 2,600 gallons for a half-pound steak; 16 gallons for three ounces of green beans; 61 gallons for an ear of corn; 26 gallons for eight ounces of grapefruit; 90 gallons for four ounces of cherries; 100 gallons for one pound of watermelon; 15 gallons for two ounces of wheat bread; 36 gallons for two ounces of rice; 40 gallons for two ounces of dried beans; 92 gallons for one half-ounce of margarine; 65 gallons for eight ounces of milk; and 410 gallons for four ounces of pork or eight ounces of chicken.

Source: *Water Newsletter*, 13 March 1981. Water Information Center, Inc. The North Shore Atrium, 6800 Jericho Tpke., Syosset, NY 11791, USA.

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Water Resources Series No.50, United Nations publication, Sales No.E.78.II.F.10. Price $US 14.00.

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Water Resources Series No.52, United Nations publication, Sales No.E.80.II.F.17. Price $US 21.00.

53. PROCEEDINGS OF THE EXPERT WORKING GROUP MEETINGS ON WATER RESOURCES DATA SYSTEMS AND WATER-USE DATA
Water Resources Series No.53, United Nations publication, Sales No.E.81.II.F.3. Price $US 12.00.

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Water Resources Series No.55, United Nations publication (in preparation).

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